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ORGANIC COMPOSITE APPLICATIONS FOR THE M1/M1A1

CONTRACT NUMBER DAAE07-85-C-R158

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By
Allen F. Pivitt
General Dynamics Land Systems Division
Warren, MI 48090
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U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
Warren, Michigan 48397-5000

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This study reviews the potential to save weight through the use of ortanic composite materials. Components incorporating these materials may be designed to replace components currently fabricated from steel or aluminum. Forty-nine M1/M1A1 components are examined.

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1.0. INTRODUCTION

This report, prepared by General Dynamics Land Systems Division (GDLS) for the U.S. Army Tank and Automotive Command under Contract DAAE07-85-C-R158, examines the potential use of organic composite materials for various components in the M1/M1A1 tank to save weight. Components incorporating these materials may be designed to replace components currently fabricated from steel or aluminum. A total of 49 M1/M1A1 components have been examined.

Continuous improvements to the M1 tank have increased its weight substantially and will continue to do so. These improvements are necessary to increase the survivability and effectiveness of the tank. Systems such as improved armor, improved and additional electronics, nuclear, biological and chemical (NBC) protection systems, and improved fire power have accounted for weight increases to the point where the current M1A1 tank weighs approximatly 65 tons. Future block improvements will add more weight to the tank. This weight can not be added without an effect on performance parameters such as acceleration, and maneuverability. Limits on reliable suspension performance are also a major concern. The increased weight also affects the tanks overall transportability.

Weight reduction will result in longer suspension component life. In particular, track pad and torsion bar life will increase, and life cycle costs will be reduced for these components. Drivetrain reliability, availability, and maintainability (RAM) should also increase as the tank is lightened, and overall operating costs will be reduced.

2.0. OBJECTIVE

Following is the objective and Scope of Work for Contract No. DAAE07-85-C-R158:

2.1. Evaluate potential applications for organic composite materials.

2.1.1. Materials to be considered for this effort shall include but not be limited to continuous or chopped fibers such as glass, graphite or kevlar in an organic matrix.

2.1.2. A reduction in weight is the highest priority but a reduction in life cycle cost is also an important factor.

2.1.3. Develop in a systematic manner a prioritized plan of potential candidates for fabrication of composite materials.

2.1.4. Select those technology developments that appear to have potential for extending the vehicle or component life with no degradation of their performance.

2.1.5. Identify the near term (1990) and the long term (2000) potential solutions.

2.1.6. This final report includes:

The estimated cost to produce the component considering the volume required for M1 production rates.

Manufacturing process which would produce the component at the lowest possible cost with adequate performance and reliability.

The estimated weight/cost savings and rationale.

Availability of material.

Ease of fabrication.

Ease of decontamination after exposure to Nuclear, Biological and Chemical (NBC) agents.

3.0. CONCLUSIONS

Weight reduction and cost savings can be obtained through the application of organic composite materials to certain components of the M1/M1A1 tank. Many of these applications could be put into service in the near future. The major obstacles appear to be the lack of knowledge regarding these materials in the combat vehicle community, the concern over flammability and NBC performance of these materials, and the lack of existence of proven applications on current vehicles.

4.0. RECOMMENDATIONS

Six recommendations have resulted from this study, and are as follows:

1. Perform detailed design analysis and life cycle cost evaluation of top ranked composite components.
2. Fabricate and field prototype composite components on actual M1/M1A1 tanks to get RAM baselines.
3. Obtain additional information and perform tests of the flammability of specific organic composite materials.
4. Obtain additional information and perform tests on NBC and decontaminant effects on composite materials.
5. Begin examination of long term and "high tech" composite material applications.
6. Educate key people on the advantages of composite materials.

The use of composite materials has grown considerably, and will continue to do so in the future. It appears to be only a matter of time before their use on military vehicles becomes common.

5.0. DISCUSSION

5.1. Component Selection

Potential components for composite material applications were selected by one of two procedures, or a combination of the two as shown in Figure 5-1. The first procedure consisted of a thorough examination of their Direct Support and General Support Maintenance Repair Parts and Special Tools List manual for the M1 and M1A1 tanks.[1-4] The components chosen for possible composite applications were based upon an initial evaluation of their complexity, environment, function, and potential weight savings. None of the components that function as armor or have armor protection were chosen, since ballistic performance was beyond the scope of the program. This process produced a large number of components for possible composite material applications.

The second method of selection involved the direct examination of actual M1 and M1A1 vehicles. This procedure provided a better "feel" for the vehicle and its components, while also providing additional information which could not be gained easily from the manuals. More components were added to the list, and some were removed through this process. The final list (Table 5-1) is the result of several iterations of the two procedures.

To facilitate evaluation, the list of components was separated into three groups with type of stress state as the evaluation criteria. The first group consisted of components with simple stress states. The second group included those components with more complex but well defined stress states. These two groups accounted for the majority of the components examined. In most cases, potential composite applications in these two groups involved relatively straightforward designs. The third group of components had unknown or undefined stress states. These components were generally more critical to the performance of the tank and the design process was also more difficult.

5.2. Figure of Merit Rating System

The Figure of Merit Rating is a number used to describe the desirability of developing a composite component to replace a current metal production component based on an initial evaluation process. The rating is not intended to be "absolute" since other factors not taken into account in the rating may affect the feasibility of fabricating a composite component. Compilation of the Figure of Merit for a number of components allows comparisons of these components to each other.

5.2.1. Methodology

Several criteria were used to determine the Figure of Merit. These criteria were organized into subsections which were assigned numerical ratings based on engineering analysis and expert opinion. Classification ratings were multiplied by a weighting factor, which represented the importance of the criteria to the overall objectives of the study. A summation of the resulting numbers provided an initial rating. This rating was converted to a zero to 100 scale for easier comparison of the results (zero being the worst rating a component can receive and 100 being the highest possible rating).

With the concept of a Figure of Merit Rating System established, the criteria to be used in the rating and the weighting factors were determined. Criteria considered during the evaluation included:

Weight Savings	Reliability
Life Cycle Cost	Maintainability
Shock and Ballistic Environment	Durability
Structure Type	Operating Environment
Stress State	Initial Cost

After further evaluation, it was decided that some of the categories could not be objectively quantified, and would therefore render the rating system unreliable. Additional discussions determined that the reliability, maintainability, durability, and operating environment criteria would be removed from the list, since these criteria could only be rated from actual data obtained from usage of composite components on vehicles.

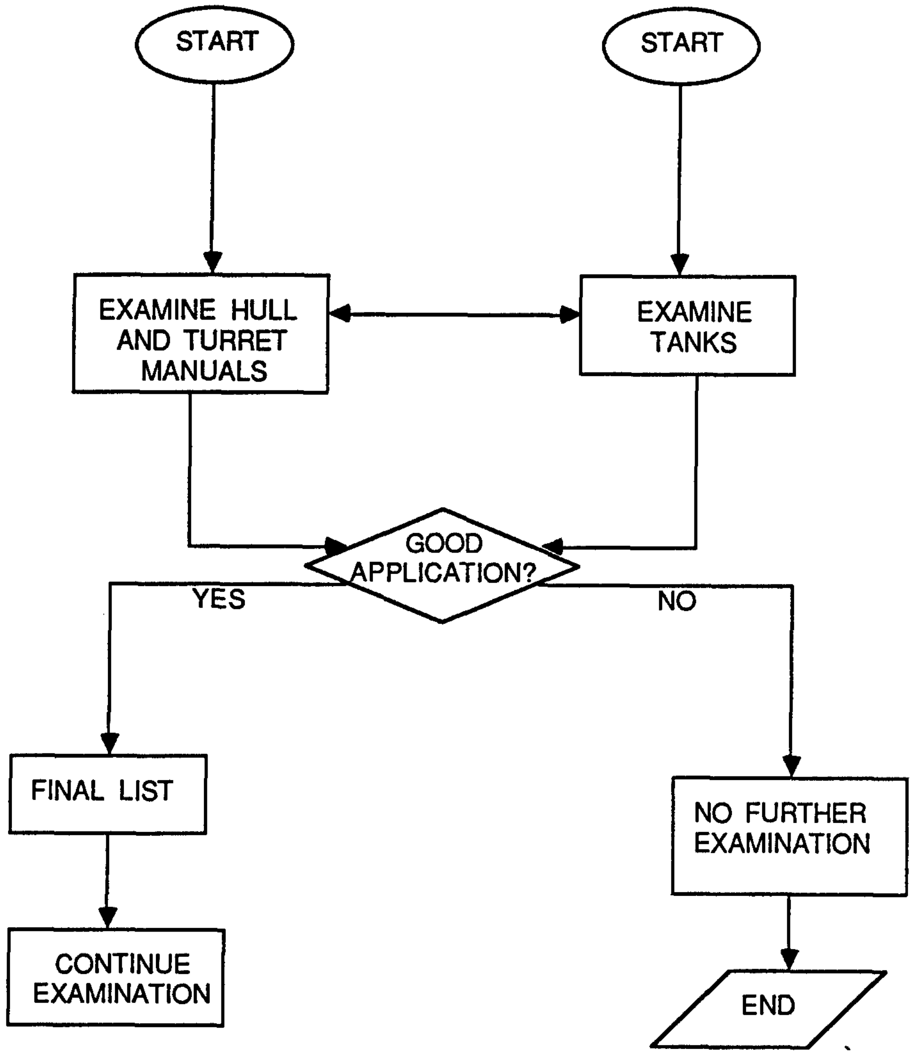

Figure 5-1. Component Selection Process

Table 5-1. Component List

Pre-Cleaner Assembly	Crew Stowage Box
Air-Intake Plenum	U-Joint Covers
Tubiaxial Fan Housing	Reservoir Assembly
Oil Cooler Ducts	Scavenger Duct
Skirt Support	Fuel Tank Shield
Gun Mount Tube	Hull Wiring Duct
Gun Mount Tube Assembly	Fire Extinguisher Bottle
Turret Platform	Fire Extinguisher Bracket
Turret Platform Deflector	Track Pad
Support Rollers	Vetronics Boxes
Domelights	Driver's Seat
Headlights	Commander's Seat
Wheel Hubs	Loader's Seat
Loader's Panel/Radio Mount	Turret Platform Support
Torsion Bar	Turret Platform Bracket
Torsion Bar Cover	Turret Platform Post
Roadarms	MRS Collimator
Final Drive Hub	Gun Barrel
Roadwheels	Turret Interior Stowage Boxes
Sponson Cover	Airflow Baffles
Rear Fenders	Propeller Shafts
Front Fenders	Gunner's Seat
Mud Guards	Ammo Doors
Ammo Racks	Turret Exterior Stowage Boxes
Gunner's Footrest	

The initial cost category was changed to implementation cost in order to provide a suitable basis for comparing components using payback data. The final categories used in the determination of the Figure of Merit ratings were:

Weight Savings
Life Cycle Cost
Shock and Ballistic Environment
Structure Type
Stress State
Implementation Cost

Once the optimum rating criteria were determined, they were divided into five classifications each to allow for distinction between components. Numerical values of one to five were assigned to these classifications with one being the least desirable characteristic and five being the most desirable.

Weighting factors were assigned to each of the criteria to establish varying degrees of importance. The factors used were subjective figures assigned to the categories by a team of engineers with experience in combat vehicle systems considering the scope of the study. Extensive iterations resulted in the following weighting factors:

CATEGORY	WEIGHTING FACTOR
Weight Savings	5.0
Life Cycle Cost	4.0
Shock/Ballistic Environment	3.0
Structure Type	3.0
Stress State	3.0
Implementation Cost	2.0

The reasoning behind these values is discussed in the description of each criteria which follows this section.

Research into a more objective method to determine weighting factors was performed. Using the Saaty Method, additional weighting factors were determined based on a survey of GDLS personnel with extensive vehicle experience. The results of this method did not fall in line the program objectives, since weight savings did not obtain a high rating.

Using these weighting factors and the classification ratings of one to five, a rating scale of 20 to 100 was produced (i.e. Rating = Sum of (Weighting Factors x Classification Rating)). These ratings were converted to a zero to 100 scale using the following relationship to produce the Figure of Merit:

$$\text{Figure of Merit} = (\text{Initial Rating} - 20) \times 1.25 \quad (1)$$

This figure was used to rank the components relative to each other.

The Figure of Merit Rating is also a measure of producibility for the candidates since it contains most of the elements of producibility. Producibility can be defined as achieving the optimum design to be produced at the lowest cost, while still meeting the required quality and performance parameters. This design must be obtainable within the required time constraints or it cannot be considered a producible design.

The final Figure of Merit Rating Sytstem is shown in Figure 5-2.

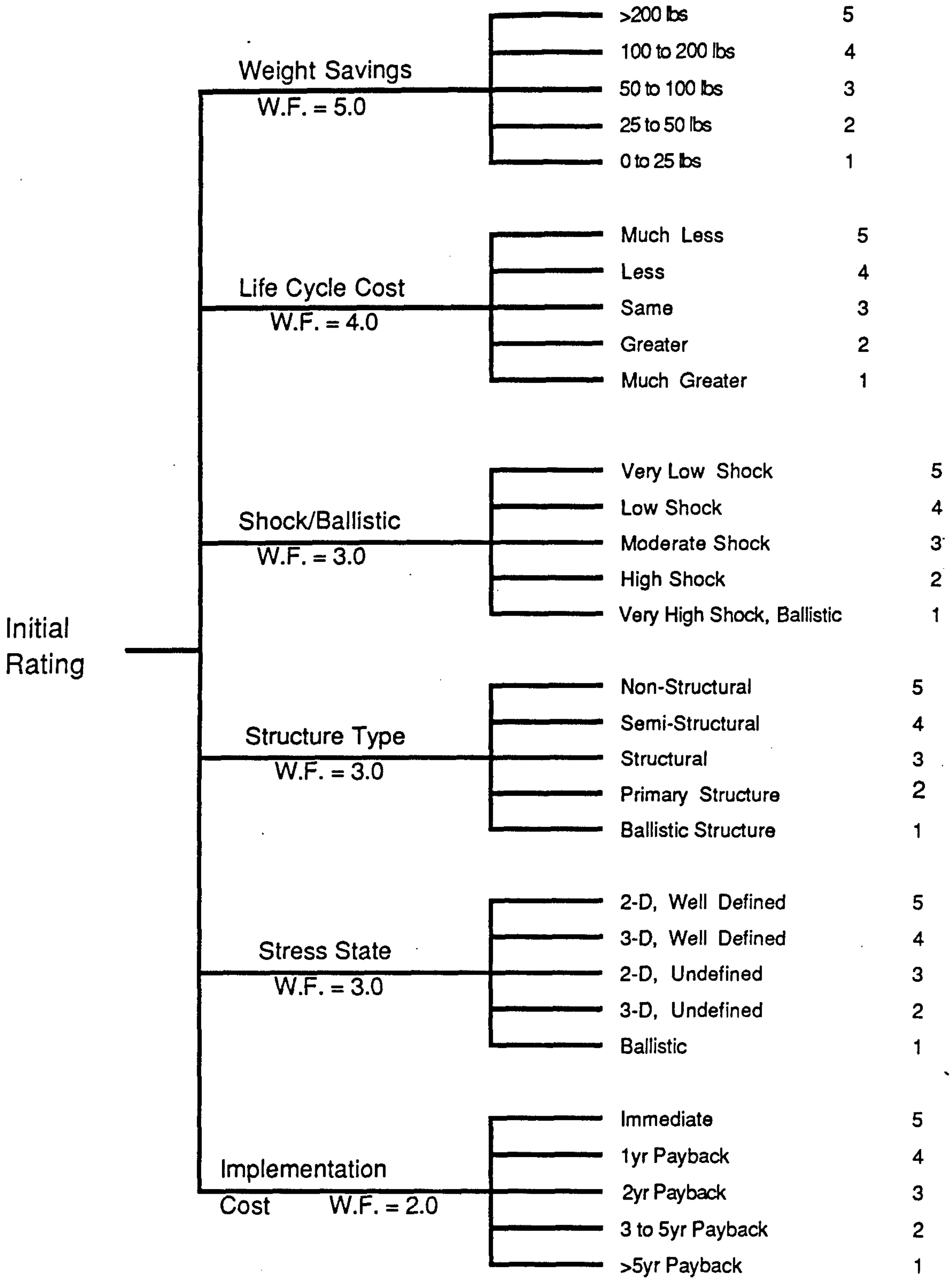

Figure of Merit = (Initial Rating - 20) x 1.25

Figure 5-2. Figure of Merit Rating System

5.2.2. Criteria Descriptions

More detailed descriptions of the criteria represented in the Figure of Merit are given below.

5.2.2.1. Weight Savings

Weight savings was listed in the Scope of Work as the highest priority in determining a composite component's desirability. Therefore, the highest weighting factor of five was assigned to this category. Based on weight savings in pounds, a classifications scale of 0-25, 25-50, 50-100, 100-200, and 200 was chosen to provide more separation in the lower ranges where most of the components examined fall. The M1/M1A1 components that were primary candidates for substitution of composite materials were for the most part nonstructural or semi-structural, and consisted primarily of smaller components which yield small weight saving up to 25 pounds. Greater weight savings will be obtained by using composites for primary structural elements such as suspension components, where the most efficient method would be a total redesign of the system for optimum advantage of these materials.

Weights for the proposed composite components were estimated using one of several methods depending upon the component being examined. Where it was felt that a composite material could be substituted on a one-for-one basis for the metal, weights were estimated by multiplying the volume of the component by the suggested composite material density. For example, this procedure was used in the case of the composite torsion bar covers where a composite tube with a wall thickness equal to the current metal tubes was recommended. Other weight estimates were based on resizing the current metal component, and calculating the proposed composite weight using this new volume. This was done for the air intake plenum where varying thicknesses of different materials were recommended for various sections. Still other weight estimates were based on totally new designs and, in a few cases, prior experience of GDLS employees.

Table 5-2 lists the weights of proposed components along with the current production equivalents.

5.2.2.2. Life Cycle Cost

Life Cycle Cost (LCC) can be defined as all costs incurred from the point in time that a decision is made to examine an item to the point in time that the item is disposed of. It includes the cost of research and development, production and facilities acquisition, fielding and sustainment, and disposal.

Research and Development - Includes all costs to the Government, defined as contractor costs plus in-house costs, of products and services necessary to bring a specific material system from concept to production.

Production and Facilities Acquisition - Includes all costs to the Government, defined as contractor costs plus in-house costs, of products and services necessary to transform the results of Research and Development into a fully operational sysem consisting of the hardware, training, and support activities necessary to initiate operations.

Fielding - Includes all costs to the Government, associated with the iterative process of introducing a new material system and simultaneously redistributing the replaced material system to a final user with sufficient resources to achieve the user's given mission objectives.

Table 5-2. Current and Potential Weights for Top Ranked Components

Part	Current Weights (Lbs.)	Composite Wieght (Lbs.)
Air Intake Plenum	211	65
Pre-Cleaner Assembly	65	43
Final Drive Hub (2 per tank)	380*	190*
Ammo Racks	408 (total)	275 (total)
Driver's Seat	110	51
Skirt Support (2 per tank)	38*	15*
Turret Exterior Stowage (2 per tank)	38*	15*
Domelights (4 per tank)	4*	1*
Headlights (2 per tank)	7*	3*
Reservoir Assembly	29	19
Oil-Cooler Ducts (2 per tank)	17*	14*
Fire Extinguisher Bottle (3 per tank)	9*	4*
Sponson Cover	15	9
Gun Mount Tube	6	4
Gun Mount Tube Assembly	31	19
Tubiaxial Fan Housing	11	6
Torsion Bar Cover (14 per tank)	7*	4*
Turret Platform	350	255
Turret Interior Stowage (typical)	7	4
Commander's Seat	104	50
Wheel Hub (16 per tank)	24*	10*
Torsion Bar (14 per tank)	123*	46*

*Weight per part

Sustainment - Includes all costs resulting from the operation, maintenance and support of the system after it is accepted into the Army inventory until it is withdrawn from the Army inventory.

Disposal - Includes all costs of disposing of the system from the time the system is removed from service to the time it is removed from the owner's possesion. In some cases, such as nuclear waste, the disposal cost can be a large portion of the life cycle cost.

Models for determining life cycle costs have been developed, however, to date, there have been difficulities in determining the life cycle costs ratings. The ideal approach was to estimate actual life cycle costs for the candidates. The unknowns in the life cycle cost equation (such as durability and maintenance) created problems in accomplishing this accurately. The standard method used to estimate these unknowns is to examine similar components that already exist in similar situations so comparisons can be made and estimates derived.

In the case of most of the M1 components being examined, there are no similar composite components. In addition, life cycle cost information on the existing components is not yet available. The scope of this contract did not allow for actual life cycle costs to be determined (GDLS has experience developing life cycle costs for composite materials, for example, a LCC analysis was performed on a Torlon fuel pump shaft) so an alternative method to determine life cycle cost ratings was used.

Implementation cost estimates provided the principal basis for developing the life cycle cost ratings. For a tank vehicle, operation and support costs account for approximately 60 percent of the total life cycle cost. Since most of the listed components are designed to last the life of the tank (as shown by the estimated failure rates), all costs incurred after the initial procurement were assumed approximately equal for the metal and the composite components. For components where it was felt that this may not be the case, the importance of each one of the cost categories that make up the lfe cycle cost was weighed and it was estimated whether a savings or cost increase would be realized by using the composite component over the current production part.

The life cycle cost ratings reflect qualitative estimates, however they provide good relative information which is most important in determining the Figure of Merits. The life cycle cost category was divided into classifications based on comparisons of LCC of the composite component to the metal component as: much less, less, the same, greater, or much greater. These classifications were assigned values of one for much greater to five for much less.

Reduced life cycle costs was stated in the scope of work as being very important, and therefore, this category is given a weighting factor of four on a scale of one to five to reflect its overall relative importance in the Figure of Merit ratings.

5.2.2.3. Shock/Ballistic Environment

Mechanical loading in a tank caused by ballistic impact and gun firing can cause failure in components that are not designed properly. Therefore, this consideration was included in determining the Figure of Merit of a component.

The initial method used to determine the shock and ballistic ratings was to calculate the impulse a component experiences from the shock of the main gun being fired, or by the ballistic requirements a component must meet. The impulse was calculated using the

equation I = MV, where I is the impulse in lb-sec, M is the mass of the component in slugs, and V is the velocity in ft/sec determined by integrating the area under the applicable shock load curves shown in the Appendix A. This method allowed numerical criteria to be assigned to the individual sections which compose the shock/ballistic category. The five criteria were: components having an impulse of zero to ten lb/sec would get a rating of five in this category, components having an impulse of ten to 20 lb/sec would receive a rating of four, components having an impulse of 20 to 30 lb/sec would receive a three, those having an impulse of 30 to 40 lb/sec would receive a two, and components having an impulse of greater than 40 lb/sec would receive a rating of one in this category.

A problem was encountered in using this methodology. The components being examined all fell into the low shock/ballistic category. This resulted from the fact that the components were generally low in mass (shock impulse is directly proportional to mass) and the selection process emphasized nonballistic, nonstructural, or semi-structural regions.

It was decided to base component shock assessments on the local shock environment of the component in the tank. The ratings shown in Tables 5-3 through 5-5 were objectively determined by the shock levels at the location of the component. Gun firing, operational ballistic shock, and high intensity shock were included in the ratings. All three types of shock loads consisted of imposing shock impulses at the interface between the specified sublocation and the component mounting bracket, including shock/vibration isolators as applicable. Three shock impulses on each of the three axis were considered. The same information and shock curves (Appendix A) used previously in the initial calculation of the impulse data were used in these ratings*. Numbers of one to five were assigned to the three types of shock encountered (five being the lowest shock levels and zero or one being the highest). These numbers were averaged and the result was rounded off to give the shock/ballistic rating.

Weighting factor for the shock/ballistic environment category is three, since it felt that this an important category, but not as important as weight savings and life cycle cost.

5.2.2.4. Structure Type

This category was included to account for the type of structure required. Initial considerations in this category included: non-structural, semi-structural, structural, primary structure and mission critical structure. The concept behind these categories assumed that it was more difficult to design a primary structure than a non-structural component. For example: a non-structural component, such as an electrical box, carries only its own weight. A semi-structural component, such a a fire extinguisher bracket, must support its own weight and a small additional weight. A structural component, such as a fender skirt support bracket, must carry a large load. This is distinguished from primary structure, such as suspension components, which must support vehicle loads. The gun barrel is a good example of a mission critical structure. If it should fail, the main function of the tank could not be performed. A mission critical structure need not be a primary structure. The mission critical section was later deleted and the ballistic structure section was added in its place. It was concluded that because a structure is mission critical does not mean that it was difficult to design using composite materials; whereas, ballistic structures are more difficult to develop using composite materials.

*GDLS is currently collecting more accurate data on shock/ballistic environments throughout the vehicle which may be used these determinations in the future.

From the Tables 5-3 through 5-5, it can be seen that about one-half of the candidates were nonstructural, with the remaining components distributed throughout the other four structure types. It is possible for a single component to fall under two of these structure type category ratings. In these cases the lower numerical category (worst case) rating was chosen.

The structure type category received a weighting factor of three to reflect its importance in the evaluation criteria.

5.2.2.5. Stress State

Applications of composites to structural or semi-structural requirements necessitates knowledge of the static and dynamic forces present, and the distribution of these forces in components. Stress distribution (from fastening and attachment loads, for example) in composite components often differs significantly from that in similar metallic components because of material properties. Where loads and distributions are well known and simple (one or two-dimensional), the design and application is straight forward (high rating). Where stresses are unknown or complex (three-dimensional), the process is less certain (low rating). The stress state can be two-dimensional or three-dimensional, while being well defined or undefined. The stress state may also be unknown or ballistic. The well defined stresses acting on a component can be accounted for in the design process, whereas the undefined and unknown stresses are more difficult to deal with.

The weighting factor for the stress state criteria is set at three, to reflect its importance in the design process.

5.2.2.6. Implementation Cost

Simply stated, the implementation costs are the costs associated with getting a working component made and installed on a vehicle. Implementation costs include development costs, initial costs, tooling costs, manufacturing costs, training costs, packaging costs, and costs of modifications to other components. This category was chosen over initial costs since it is more useful and applicable. Most of the components examined do not require any special training cost or changes to their components, since they were direct replacements for the existing components. Manufacturing cost estimates were obtained from outside sources for some components, while others were estimated by GDLS personnel. Due to the low production rates of the M1, tooling costs and in some cases material costs may be major factors in the implementation costs. Additional information, including current component cost and estimated failure rates, (the number of spare parts required to support 100 tanks for one year), were obtained from inside the GDLS organization to assist in the development of more accurate implementation cost ratings. Candidate composite component costs were estimated by GDLS personnel.

The Implementation costs were represented in the Figure of Merit through the use of payback periods. Payback was determined from the following formula:

$$\frac{(S - (T + R + M + C + Q) \times 0.5}{T + R + M + C + Q} \times 100 = \%\text{Payback for Specific time Period} \qquad (2)$$

Where S = Cost Savings for Associated Time Period Based on Initial Cost, T = Tooling Costs, R = Research and Development Cost, M = Manufacturing Costs, C = Cost of Changes to Other Components, and Q = Training Costs. The factor of 0.5 in the

numerator represents the proportion of savings to GDLS and the Government through the Value Engineering Change Proposal (VECP) program. This category was divided into the following classifications: greater than five year payback, three to five year payback, two year payback, one year payback, and immediate payback. These classifications received rating of one to five respectively.

The weighting factor assigned to the implementation cost category was two. The life cycle cost was the more important cost and was weighted accordingly. These two cost categories together placed appropriate combined emphasis on cost.

All cost information provided for current M1/M1A1 production components in this study was obtained from within GDLS. These are the costs of components that the U. S. Government paid for spare parts. These were the most complete cost data that could be obtained. Some of the cost estimates provided for the composite components have been obtained from outside manufacturing sources, while other have been estimated by GDLS personnel familiar with the composite materials field. Any cost information provided should be used only for the purpose of comparisons in this study.

5.3. Figure of Merit Example

Following is an example of the determination of the Initial Rating and the Figure of Merit for the torsion bar cover. The current cover is constructed from aluminum. The proposed cover would be fabricated from pultruded fiberglass/polyester.

Weight Savings:

Estimated weight savings = 2.9 lbs/cover x 14 covers/tank = 40.6 lbs/tank

(weight savings rating = 2) x (weighting factor = 5) =10

Life Cycle Cost:

(Life Cycle Cost Rating (less due to lower initial cost) = 4) x (weighting factor = 4) =16

Shock/Ballistic Loads:

(Low shock environment = 4) x (weighting factor = 3) = 12

Load Intensity:

(Non-Structural = 5) x (weighting factor = 3) = 15

Stress State:

(2-D, Well Defined = 5) x (weighting factor = 3) =15

Implementation Cost:

Tooling Cost = $16,800
First Year Savings = $3.50/tube x 14 tubes/tank x 840 tanks/year x 2 (spares) - Tooling Costs

= $82,320 - $16,800 = $65,520

1st Year Payback = 65,520/16,800 = 3.9 = 390%
(very small = 5) x (weighting factor = 2) = 10

Initial Rating = 10 + 16 + 12 + 15 + 15 + 10 = 78
Figure of Merit = (78 - 20) x 1.25 = 72.5

A similar calculation for each candidate was performed, and the rank order determined.

In addition to the Figure of Merit Rating System and its associated parameters, some components may be eliminated due to NBC considerations, flammability requirements, and toxicity factors. These considerations were addressed separately for each candidate component being evaluated.

5.5. Component Ratings

Component rating were put into tabular form and are shown in Tables 5-3 through 5-5. Table 5-3 includes the components that have simple stress states, and therefore received a rating of a five in the stress state category. Most of the candidates in this list are boxes, covers, lights and fenders. All of the weight savings, except for the air intake plenum, are in the 0 to 25 pound range, since these are relatively small parts. All of these components are nonstructural, or semi-structural.

Table 5-4 contains the candidates with well defined stress states. These are two-dimensional stress states, with the exception of the torsion bar which has a three-dimensional stress state. Within this list can be found some larger weight saving opportunities such as the torsion bars and crew seats. Most of the components in this list are structural components.

Table 5-5 lists the candidates with undefined or unknown stress states. Most suspension components are in this list since the stresses in these parts depend on terrain and vehicle dynamics, and may differ in metal and composite designs. These candidates tend to be primary structural components where greater weight savings can result.

Table 5-6 presents the components listed according to their Figure of Merit rating. Most of the top ranked components have the potential to provide large weight savings, or cost savings. The Figure of Merit rating system worked well in the evaluation of these components.

5.5. Composite Application Concepts

After the initial compilation of the Figure of Merits for the 49 components, an arbitrary cutoff point at a Figure of Merit of 56 was chosen for further consideration. The resulting top ranked 22 components, of Table 5-6, were examined in more detail. Composite design concepts were developed for these components and are described below. The description includes the component name followed by its associated Figure of Merit, the current and proposed materials, weight, and costs. The description also includes paragraphs providing the function of the component, the suggested method of manufacturing the composite replacement component, and related key issues.

Table 5-3. Component Ratings - Simple Stress States

Part Name	Weight Savings	Life Cycle Cost	Shock/Ballistic Environment	Structure Type	Stress State	Implementation Cost	Figure of Merit
Vetronics Boxes	1	3	2	5	5	2	46
Turret Int. Stowage	1	3	4	5	5	3	56
Crew Stowage Box	1	3	2	5	5	3	49
Turr. Ext. Stowage	1	4	3	5	5	5	63
Hull Wiring Duct	1	3	2	5	5	4	51
U-Joint Covers	1	2	4	5	5	1	46
Sponson Covers	1	4	2	5	5	5	59
Pre-Cleaner Assembly	2	4	4	5	5	5	73
Scavenger Duct	1	3	4	5	5	2	54
Airflow Baffles	1	1	4	5	5	1	41
Oil Cooler Ducts	1	3	4	5	5	5	61
Domelights	1	4	3	5	5	5	63
Headlights	1	4	3	5	5	5	63
Mud Guards	1	3	3	5	5	1	48
Front Fenders	1	3	2	5	5	4	51
Rear Fenders	1	3	3	5	5	1	48
MRS Collimator	1	4	2	4	5	5	55
Gun Mount Tube	1	4	2	5	5	5	59
Gun Mount Tube Assy.	1	4	2	5	5	5	59

Table 5-4. Component Ratings - Well Defined Stress State

Part Name	Weight Savings	Life Cycle Cost	Shock/Ballistic Environment	Structure Type	Stress State	Implementation Cost	Figure of Merit
Torsion Bars	5	2	4	2	4	1	56
Torsion Bar Cover	2	3	4	4	5	3	59
Fuel Tank Shield	1	3	4	5	5	2	54
Reservoir Assembly	1	4	4	4	5	5	63
Fire Ex. Bracket	1	3	2	4	5	2	43
Fire Ex. Bottle	1	4	5	3	5	4	60
Driver's Seat	3	4	2	3	5	5	64
Gunner's Seat	2	3	4	3	5	2	53
Loader's Seat	2	3	4	3	5	2	53
Commander's Seat	3	2	4	3	5	1	56
Turret Platform Support	1	3	4	3	5	2	46
Turret Platform Bracket	1	3	4	3	5	2	46
Turret Platform Defletor	1	3	4	5	5	1	51
Turret Platform Post	1	3	4	3	5	2	46
Loader's Panel Bracket/ Radio Mount	1	3	4	3	5	4	51
Gunner's Footrest	1	3	4	3	5	3	49
Air Intake Plenum	4	3	4	5	5	5	80
Tubiaxial Fan Housing	1	3	4	5	5	4	59
Propeller Shafts	1	2	4	1	5	1	31
Skirt Support	3	4	2	3	5	5	64

Table 5-5. Component Ratings - Undefined or Unknown Stress States

Part Name	Weight Savings	Life Cycle Cost	Shock/Ballistic Environment	Structure Type	Stress State	Implementation Cost	Figure of Merit
Ammo Racks	4	4	4	3	3	5	70
Ammo Doors	3	2	1	1	1	1	19
Turret Platform	3	4	4	3	3	3	59
Road Arms	5	3	2	2	2	2	49
Final Drive Hub	5	4	4	2	3	5	73
Wheel Hubs	5	3	2	2	2	5	56
Support Rollers	3	3	3	4	2	5	55
Track Pad	1	1	2	2	1	1	8
Roadwheels	5	3	2	2	2	4	54
Gun Barrel	4	1	2	1	1	1	23

Table 5-6. Component Rankings

Part	Figure of Merit	Part	Figure of Merit
Air Intake Plenum	80	Front Fenders	51
Pre-Cleaner Assy.	73	Turret Platform Deflector	51
Final Drive Hub	73	Loader's Panel/Radio Mt.	51
Ammo Racks	70	Crew Stowage Box	49
Driver's Seat	64	Gunner's Footrest	49
Skirt Support	64	Roadarms	49
Turret Exterior Stowage	63	Mud Guards	48
Domelights	63	Rear Fenders	48
Headlights	63	U-Joint Covers	46
Reservoir Assembly	63	Turret Platform Support	46
Oil Cooler Ducts	61	Turret Platform Bracket	46
Fire Extinguisher Bottle	60	Turret Platform Post	46
Sponson Cover	59	Vetronics Boxes	46
Gun Mount Tube	59	Fire Extinguisher Bracket	43
Gun Mount Tube Assembly	59	Airflow Baffles	41
Tubiaxial Fan Housing	59	Propeller Shafts	31
Torsion Bar Cover	59	Gun Barrel	23
Turret Platform	59	Ammo Doors	18
Turret Interior Stowage	56	Track Pad	8
Commander's Seat	56		
Wheel Hubs	56		
Torsion Bar	56		
MRS Collimator	55		
Support Rollers	55		
Scavenger Duct	54		
Fuel Tank Shield	54		
Roadwheels	54		
Gunner's Seat	53		
Loader's Seat	53		
Hull Wiring Duct	51		

The concepts that were developed are based on replacing the current metal components with "bolt-in" composite parts leaving the interface points the same. Thus, the current design was adapted to use composite materials in most cases. This procedure is not always the best method to develop composite components, however it was felt that interchangability with the production components is important to facilitating the application of composite materials to the current tank program. All composite concepts developed are based on having equal reliabilities and durabilities as compared to the current production parts, however, this can only be assured with detailed design and testing. Actual information on reliabilities and durabilities can only be gained by fielding actual components. Suggested manufacturing methods are based on production rates of less than 900 tanks per year.

5.5.1. Air Intake Plenum (Figure of Merit = 80)

	CURRENT	PROPOSED
Material	Aluminum	Nylon, Polyester/E-Glass
Weight (lbs)	211	65
Cost (Engineering Estimate)	$4,305	$551

The air intake plenum is in the engine compartment, and its function is to clean and direct air into the engine. Intake air is initially cleaned in the pre-cleaner assembly to remove large pieces of debris. The pre-cleaner assembly is attached to the top of the air intake plenum. The air is then filtered again by three v-pack filters, located inside the air intake plenum, to remove the finer debris which could damage the engine if allowed to enter. The air then passes through the remaining portion of the plenum to the engine. It achieved its high Figure of Merit from its large potential weight savings, and its potential life cycle and implementation cost savings.

The present production air intake plenum is fabricated from several pieces of aluminum sheet welded together to form the desired shape, which could be optimized for better airflow. It must withstand three psi of pressure without leaking. The removable v-pack filters are held in place by clamping devices which apply pressure to the end plate of the plenum. The welds on the current production components account for a large percentage of the total cost of the part. The intake air enters at atmospheric temperatures so that special heat resistant materials are not required. Additional loads are placed on this structure from the weight of the pre-cleaner assembly.

The proposed composite air-intake plenum would be fabricated from nylon and polyester/E-glass composite. The curved section of the plenum would be fabricated from rotational molded nylon of a 1/4" thickness. Some of the current square corners could be rounded for better airflow. A low cost mold is recommended for this process. The remaining section of this component would be made from E-glass fabric in a polyester matrix of approximately 1/8" thick in most places. Flame retardant materials and coatings would be desirable for use on this component to resist any small engine compartment fires which could otherwise damage this structure and ultimately the engine. Serveral pieces would be riveted and bonded together to form the box. Greater thicknesses are required on the ends of the box to resist deflection caused by the installation of the v-pack filters. Fittings for the pre-cleaner attachments would also be riveted in place. Three separate molds would be required for the Hand Lay-Up fabrication of these components. This box could be molded in one piece, but this would add greatly to the cost and more extensive design changes would be necessary.

An air-tight seal between the separate pieces and the pre-cleaner assembly is required, since any dust that enters the engine could render it inoperable. Extensive testing is required for the air intake system before a design change can go into production. A sketch of the composite assembly is shown in Figure 5-3.

5.5.2. Pre-Cleaner Assembly (Figure of Merit = 73)

	CURRENT	PROPOSED
Material	Aluminum	Ploysester/E-Glass
Weight (lbs)	65 40	
Cost (Engineering Estimate)	$1,668	$1,100

The pre-cleaner removes large particles of debris from the intake air before it enters the air intake plenum. The production pre-cleaner assembly is bought as a single unit from the supplier. The housing is fabricated from a number of pieces cut out of aluminum sheet and welded together to form the final complex shape. Removable filters are contained within the unit. The pre-cleaner assembly received a high Figure of Merit from its life cycle and implementation cost savings potential.

With a few minor design changes the pre-cleaner could be molded using a squeeze molding process in two or three pieces. A polyester/E-glass sytem would be used for its low cost. Again, flame retardant coatings and resins are recommended for this component. The present internal filters would remain to reduce costs. Figure 5-4 shows the present assembly and the composite concept. Extensive testing is also required on this component to ensure air-tight seals.

5.5.3. Final Drive Hub (Figure of Merit = 73)

	CURRENT	PROPOSED
Material	Steel	Epoxy/Graphite/S-Glass
Weight (lbs)	380 each	190 each
Cost (Engineering Estimate)	$1,502	$1,100

The final drive hub transmits power from the engine drive to the track through the two sprockets mounted to the hub. There is a single hub located on each side of the tank. The production hubs are bought as castings from a supplier. Machining is required to obtain the desired geometry. The final drive hub obtained its high Figure of Merit from the high weight savings potential. This weight savings would make the hub much easier to service. An additional potential advantage of the composite final drive hub may be reduced acoustic signature of the vehicle, and reduced noise transmission to the crew compartment. The final drive hub along with composite mud guards (fabricated by GDLS) are shown in Figure 5-5.

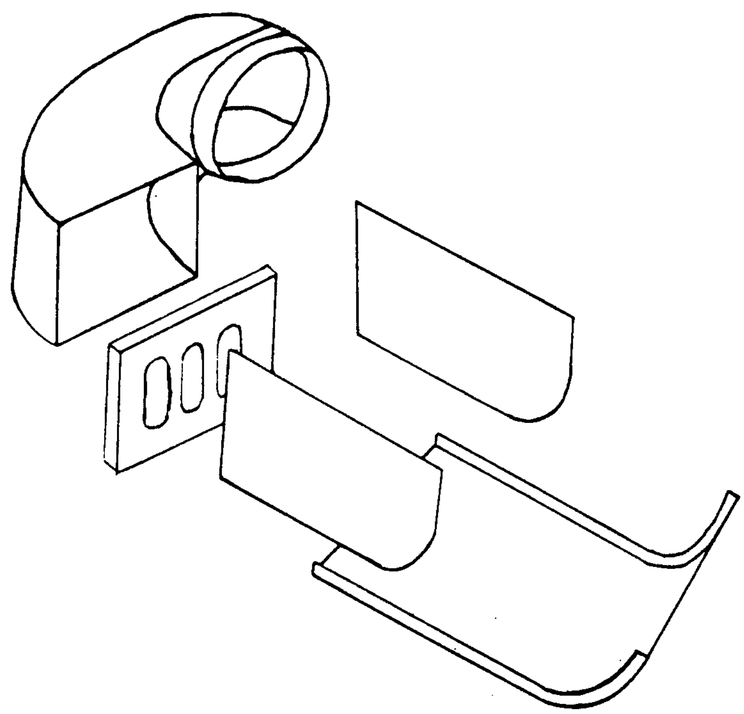

Figure 5-3. Composite Air Intake Plenum Concept

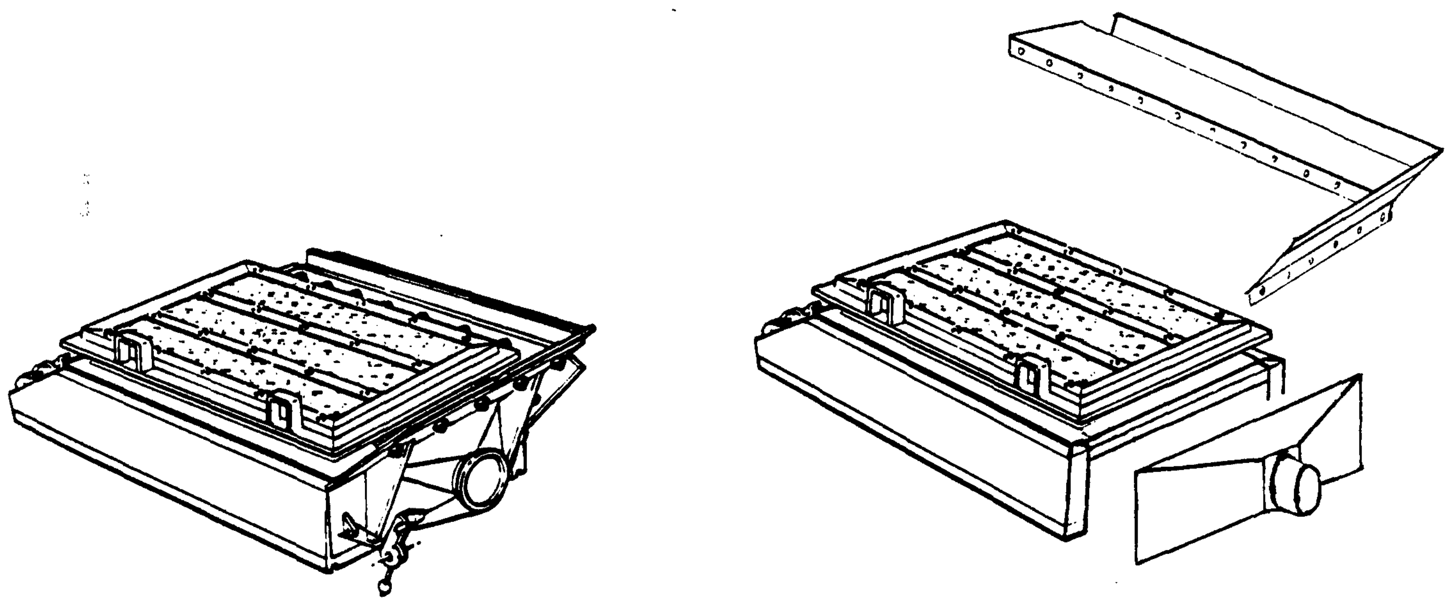

Figure 5-4. Production Pre Cleaner and Composite Pre-Cleaner Concept

The proposed composite drive hub would be fabricated from a hybrid of S-glass and graphite fibers in an epoxy matrix. The desirable method of fabrication is filament winding for its low cost tooling. However, an additional mold may be required in order to obtain the desired final shape. The areas of main concern are the bolted joints at the spocket and at the pont of attachment of the hub and engine drive. Loads on the drive hub are approximately 116,000 ft-lb of torque from the engine. Therefore, special considerations must be given to the holes in the hub which allow mud to escape from between the hub and track. The ballistic performance of a composite hub must be considered too. A final drive hub failure would render a vehicle immmobile. Therefore, additional armor may be required to protect the hub from small arms fire.

5.5.4. Ammo Racks (Figure of Merit = 70)

	CURRENT	PROPOSED
Material	Aluminum	E-Glass/Epoxy
Weight (lbs)	408	275
Cost (Engineering Estimate)	$877	$800

The ammo racks are located inside the turret bustle and hull. They are used to store the rounds of ammunition before they are spent. Present construction consists of aluminum tubes held in an aluminum framework. There is storage for 40 rounds in the M1A1. These ammo racks for the M1A1 are procured by GDLS, and manufactured in Germany. The high Figure of Merit is due to the relatively high potential weight savings which may be obtained through the use of composite materials.

One approach to reduce weight in the ammo racks through the use of composite materials is to filament wind the storage tubes with an E-glass/epoxy composite. Sufficient strength in this tube is required to support the total weight of the round. Most of the other current hardware would be used if this approach were taken. Methods of attachment would include bonding, riveting, and wound-in as opposed to the welds used presently. Further replacement would include the framework which holds the tubes. There is also the possibility of developing a total new ammo rack, which would require a large scale effort.

The major concern in replacing the current tubes with composite tubes is that the tubes should keep the rounds isolated as much as possible to prevent additional rounds from exploding if one round is set off. Extensive testing would be required for performance comparisons between the composite concepts and the current metal racks. A heavier composite tube than the one suggested may be required to meet the performance objectives.

Typical ammo rack assemblies are shown below in Figure 5-6.

5.5.5. Driver's Seat (Figure of Merit = 64)

	CURRENT	PROPOSED
Material	Aluminum	XMC
Weight (lbs)	110	51
Cost (Engineering Estimate)	$1,648	$750

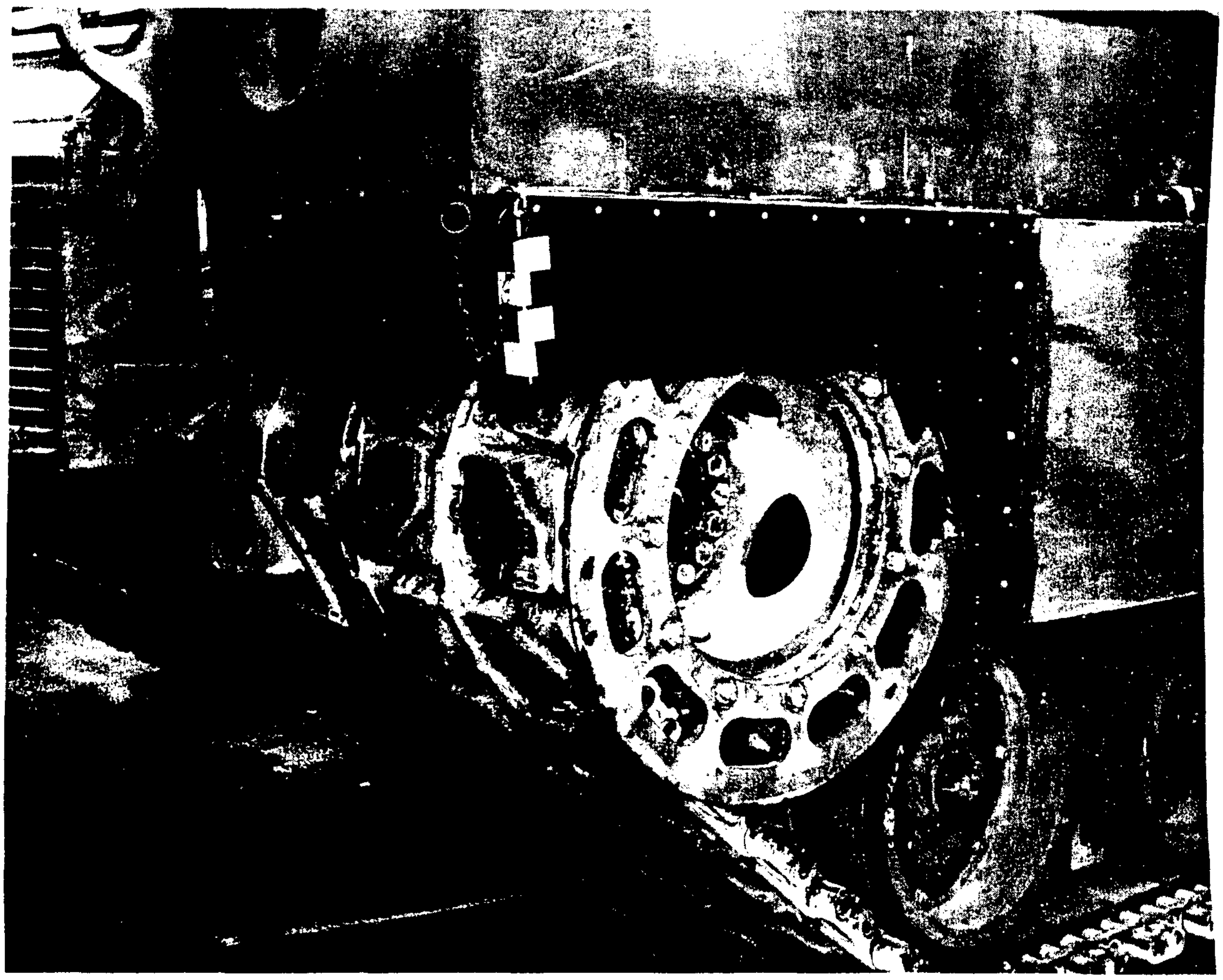

Figure 5-6. Final Drive Hub and Composite Mud Guards

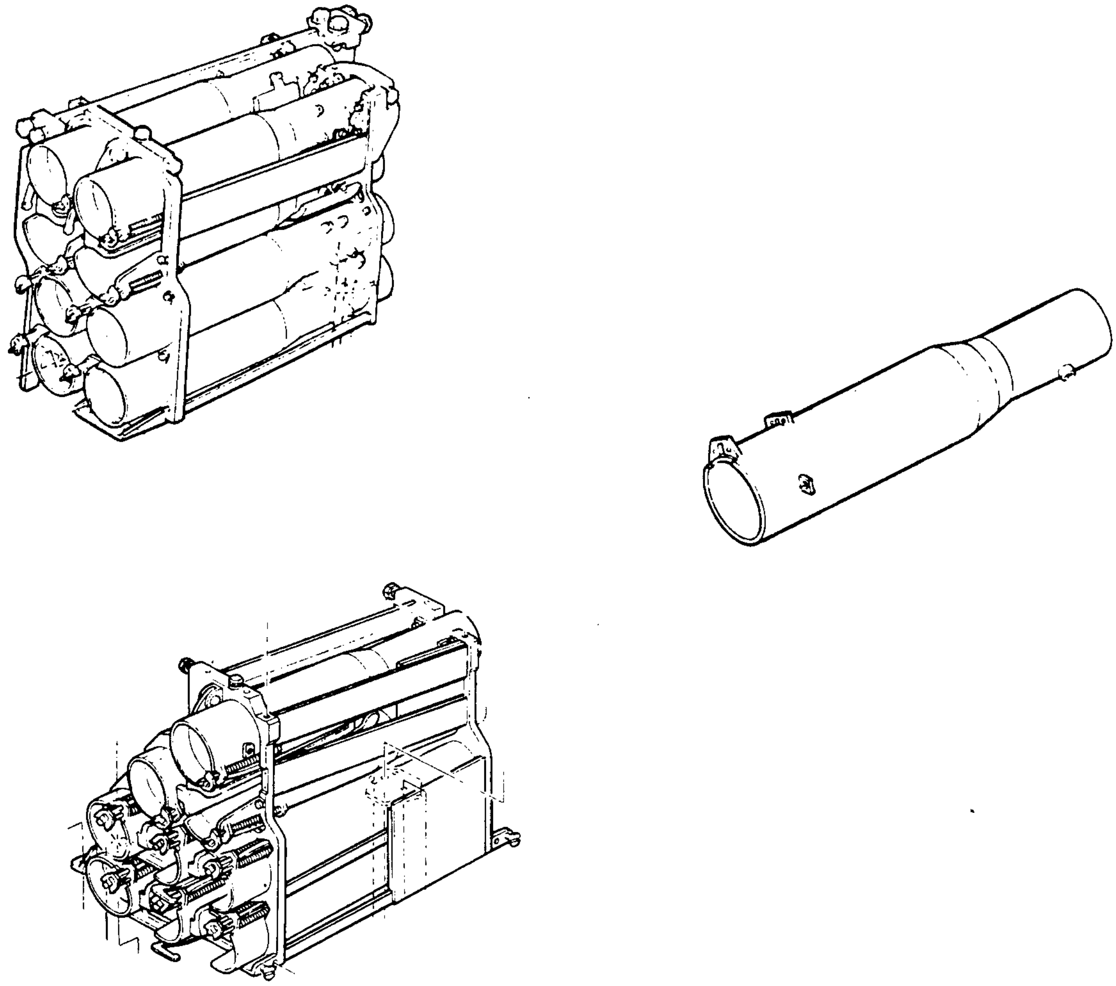

Figure 5-6. Ammo Racks and Ammo Rack Tube

The driver's seat is a multi-adjustable seat for the driver, and is located in the driver's compartment of the tank. Currently, the seat is fabricated out of 1/4" aluminum sheet welded together to form the main section of the seat. The large number of welds make this seat costly to produce. The driver's seat received its high Figure of Merit due to the potential weight and life cycle and implementation cost savings.

A composite driver's seat would eliminate most of the welds on the seat assembly. Fewer parts would be required, although most of the current adjustment hardware and the seat cushions would be retained. The seat must support the weight of a man under various G-loads, and it also must withstand the localized loads produced by the adjustment mechanisms. Parts that would be replaced with composite materials include the two lower mounting brackets, the main seat structure, the upper seat back, and the front cove. XMC would be used in the compression molding process needed to fabricate these parts. A sketch of the complete driver's seat and the composite parts are shown below in Figure 5-7.

5.5.6. Front Skirt Support (Figure of Merit = 64)

	CURRENT	PROPOSED
Material	Steel	Epoxy/S-Glass
Weight (lbs)	38 each	15 each
Cost (Engineering Estimate)	$230	$75

The front skirt support restricts the vertical movement of the front fender skirt. Currently, the tapered I-Beam shaped structure is welded from six pieces of armor steel plate. The large end of this structure bolts to the hull, and the small end accepts a locking mechanism on the front skirt. There is one of these supports located on each side of the tank. The weight savings obtained by the composite skirt support resulted in its high Figure of Merit.

A composite replacement would consist of a larger beam shaped structure, which would be filament wound using S-glass fibers in a rectangular cross section. The large end of the structure would be wound in place to provide a strong attachment for mounting. The section would be cut axially on opposite sides into two pieces. These pieces would be fastened back to back to form the I-Beam. The composite structure would be designed to have strength equal to the present metal part. The end fitting at the skirt end would remain steel to provide good wear characteristics; however, modifications would be necessary to allow it to be bolted or riveted to the composite beam. Sketches of the present skirt support and the composite replacement are shown in Figure 5-8.

5.5.7. Turret Exterior Stowage Boxes (Figure of Merit = 63)

	CURRENT	PROPOSED
Material	Aluminun	Cross-Linked Polyethylene
Weight (lbs)	38	15
Cost (Engineering Estimate)	$266	$75

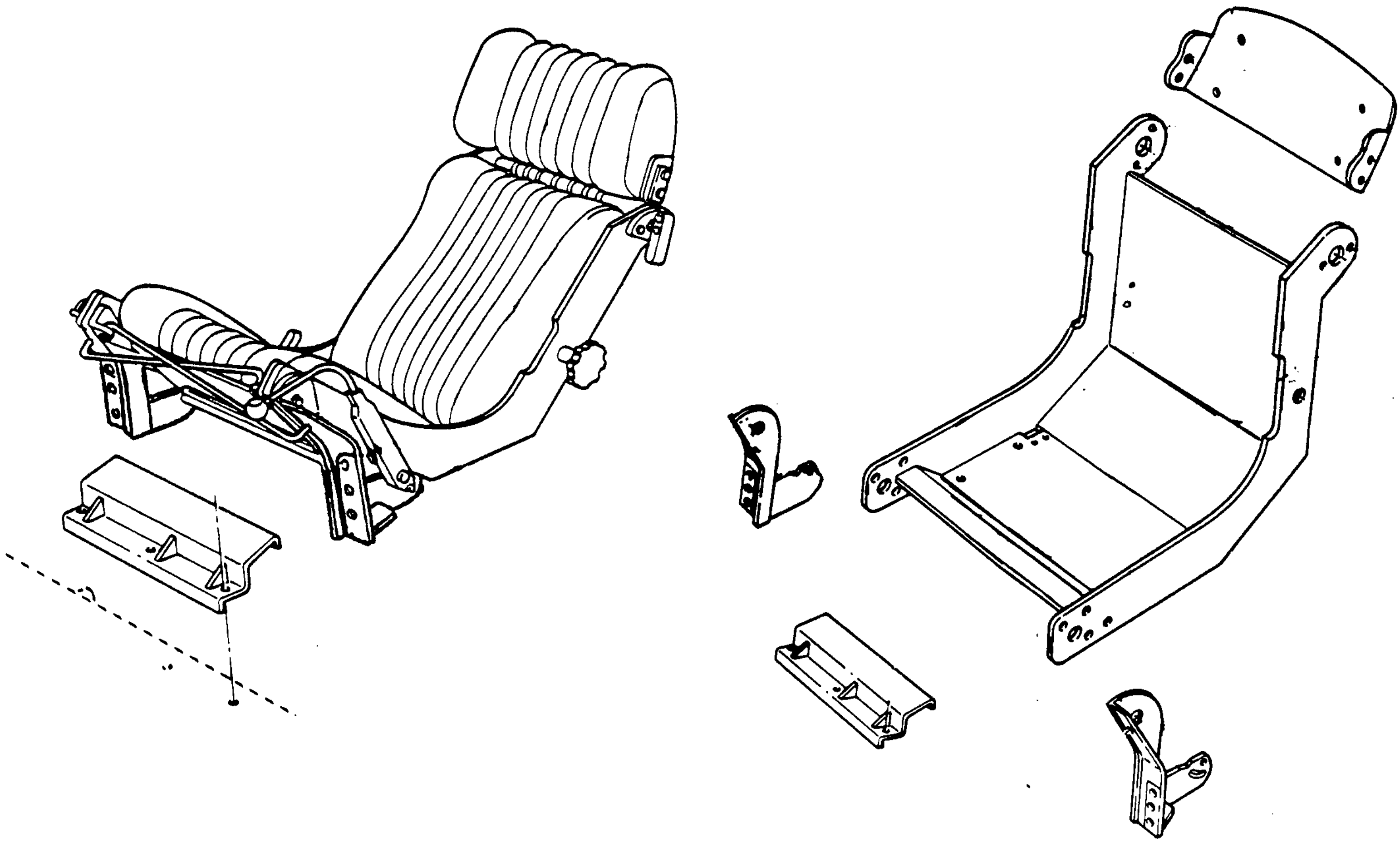

Figure 5-7. Composite Driver's Seat Component Concepts

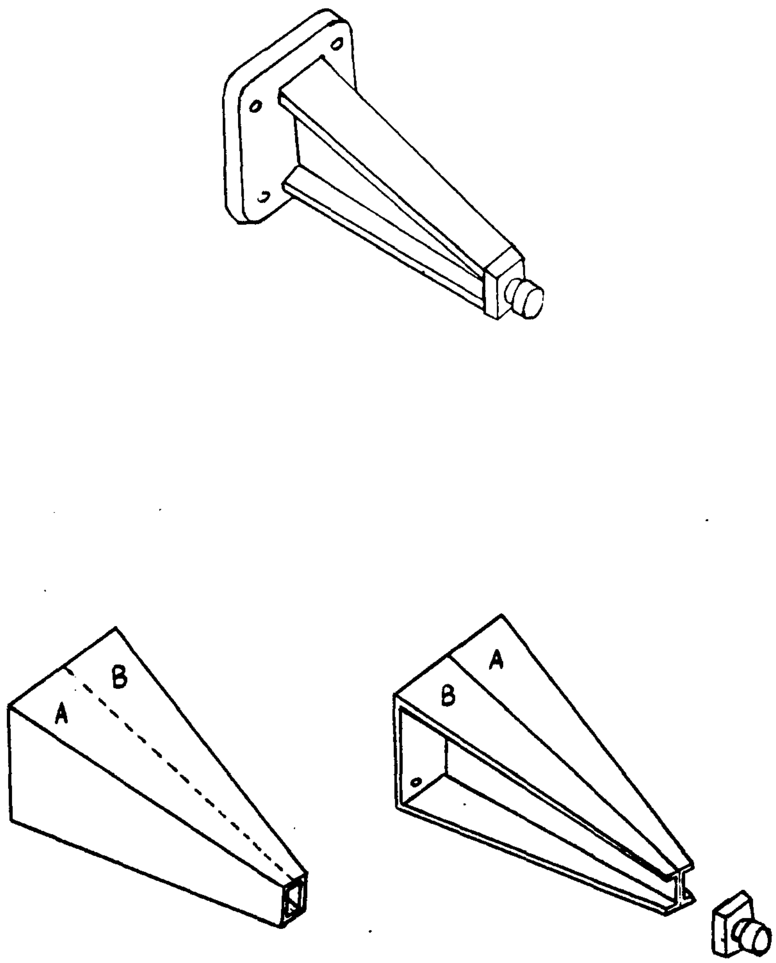

Figure 5-8. Production Skirt Support and Composite Skirt Support Concept

The two turret exterior stowage boxes are located along each side of the turret. They are used by the crew to store equipment and other miscellaneous items. The current boxes are fabricated from separate pieces of sheet aluminum welded together. There is the potential for life cycle and implementation cost savings by fabricating these boxes out of cross-linked polyethylene.

Rotational molding would be used in the fabrication of the plastic turret exterior stowage boxes. This process has been chosen for its low cost tooling. The left and right stowage boxes would be molded together, with the top being molded separately. In addition to the Cross- linked polyethylene material, rotational molded nylon has been considered for its higher stiffness; however, the cross-linked polyethylene has better performance at the low temperatures that must be met. Hardware for these boxes would be riveted in place. This type of stowage box construction is currently being developed under the VECP system used at GDLS. A sketch of an exterior stowage box is shown in Figure 11.

5.5.8. Domelight (Figure of Merit = 63)

	CURRENT	PROPOSED
Material	Aluminun	Thermoplastic
Weight (lbs)	4	1
Cost (Engineering Estimate)	$323	$90

There are four domelights located throughout the interior of the tank which provide working light for the crew. The current domelight housings are made of cast aluminum and also contain a spare light bulb. They must withstand a pressure test for leakage. The internal temperature of the present light reaches a maximum of about 240°F. They received the high Figure of Merit from the potential to save both life cycle and implementation costs.

A plastic domelight should be cheaper and easier to produce than the current design. The main concern is that a plastic capable of withstanding the high temperature produced by the light bulb must be chosen. A thermoplastic such as polyethersulfone should withstand the internal temperature of a plastic domelight, even though this temperature will be higher than the present domelight due to less heat dissipation. The main housing of the domelight would be injection molded in two pieces, including a base which would use the present mounting holes, and a tinted screw-on lens. All internal components would be ultrasonically welded into place. The four domelights per tank will help to offset the mold costs. A sketch of the domelight concept is shown below in Figure 5-10.

5.5.9. Headlight (Figure of Merit = 63)

	CURRENT	PROPOSED
Material	Aluminun	Cross-Linked Polyethylene
Weight (lbs)	7	3
Cost (Engineering Estimate)	$262	$85

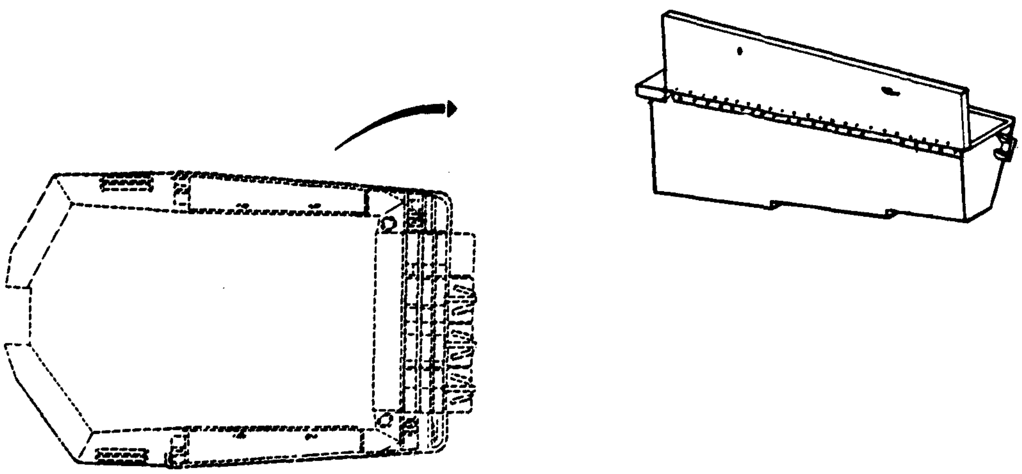

Figure 5-9. Exterior Stowage Box

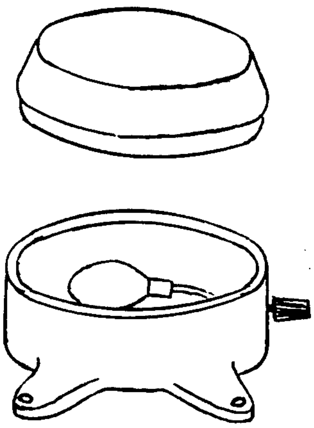

Figure 5-10. Plastic Domelight

The two headlight assemblies are mounted on the front of the tank. Each assembly contains the main headlight and a smaller blackout light. Identical assemblies are used for both the right and left headlights. The main housing is made of cast steel. The potential life cycle and implementation cost savings resulted in the high Figure of Merit for this component.

The headlight should be manufactured by rotational molding cross-linked polyethylene. Using this method it is easily possible to make a right and left hand assembly if desired. One mold would produce two parts. The total number of parts should also be reduced by designing a simpler unit. Retained hardware would include both of the lenses, bulbs and wiring. The lenses would be held in place by screw-in retaining rings. Present mounting holes would be retained. A sketch of this concept is shown below in Figure 5-11.

5.5.10. Hydraulic Oil Reservoir (Figure of Merit = 63)

	CURRENT	PROPOSED
Material	Aluminun	Cross-Linked Polyethylene
Weight (lbs)	29	19
Cost (Engineering Estimate)	$750	$185

The hydraulic oil reservoir stores hydraulic fluid for use by the tank. It is located in the turret basket of the tank. The current reservoir is assembled from several pieces of varying thicknessses of aluminum. Approximate dimensions are 23"h X 30" l X 13"w. The potential cost savings account for its high ranking.

The proposed concept is to rotational mold the reservoir from nylon. Bulkhead type fittings would be used for all connections. The overall shape would closely resemble the current part. Performance requirements include a leakage test at 3 psig of pressure for five minutes. Assembly of internal components would remain the same. A sketch of this concept is shown below in Figure 5-12.

5.5.11. Oil Cooler Ducts (Figure of Merit = 61)

	CURRENT	PROPOSED
Material	Aluminun	Polyethylene/E-Glass
Weight (lbs)	17	12
Cost (Engineering Estimate)	$318	$295

The oil cooler ducts channel air in between the exterior of the tank and the oil cooler fans. There are two of these ducts located at the rear of the tank in the engine compartment. The present ducts are fabricated from thin sheet aluminum. The oil cooler ducts are one of the top ranked components for the potential life cycle and implementation cost savings obtained by producing these components out of composite materials.

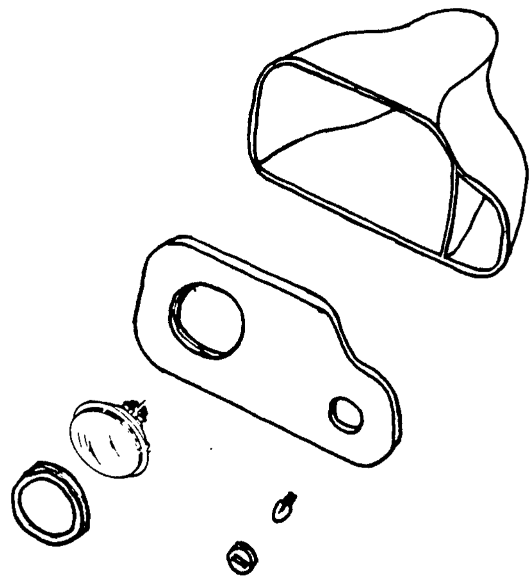

Figure 5-11. Rotational Molded Headlight Concept

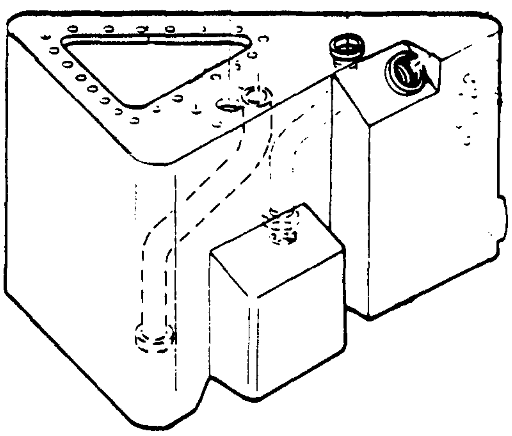

Figure 5-12. Hydraulic Oil Reservoir Concept

Composite oil cooler ducts would be fabricated from a polyester/E-glass composite using the hand lay up or resin transfer molding process. Again, flame retardant resins and coatings are recommended. Local reinforcements would be used at the mounting points. An oil cooler duct is shown below in Figure 5-13.

5.5.12. Fire Extinguisher Bottle (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Epoxy/E-Glass
Weight (lbs)	11	6
Cost (Engineering Estimate)	$216	$200

There are three fire extinguisher bottles located in the interior of the tank. They are essentially pressure vessels which contain the fire extinguishing Halon 1301 chemical. Internal operating pressure of the bottle is 1,800 psig with an internal volume of 204 cubic inches of water at 70°F. It may be possible to save life cycle costs and implementation costs by switching to a composite bottle.

A composite fire extinguisher bottle can be filament wound using an epoxy/E-glass composite. An inner liner would be needed to prevent leaks. Such pressure vessels are presently being built commercially for a number of uses. The fire extinguisher bottle and valve assembly is shown below in Figure 5-14.

5.5.13. Sponson Cover (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Polyester/E-Glass
Weight (lbs)	15	9
Cost (Engineering Estimate)	$186	$99

The sponson covers cover the sponson stowage boxes. There are two covers on the M1 and one cover on the M1A1. The production pieces are stamped aluminum with the required hardware welded in place. The high Figure of Merit is due to the potential cost savings associated with the procurement of a composite sponson cover.

A composite sponson cover would be hand-layed up using E-glass fabric and chopped strand mat and polyester resin. A plaster or plastic mold can be made using the present sponson cover as a model. Some modifications are desirable to add additional stiffness. These covers must be strong enough to support a man's weight. The current hardware would be used on the composite cover. Several methods of attaching this hardware including bonding, bolting, or riveting could be used. Several prototypes of fiberglass sponson covers were fabricated in 1984 and 1985 in the GDLS Lab under an Internal Research and Development program before this contract was awarded. Figure 5-15 shows a picture of the composite sponson cover.

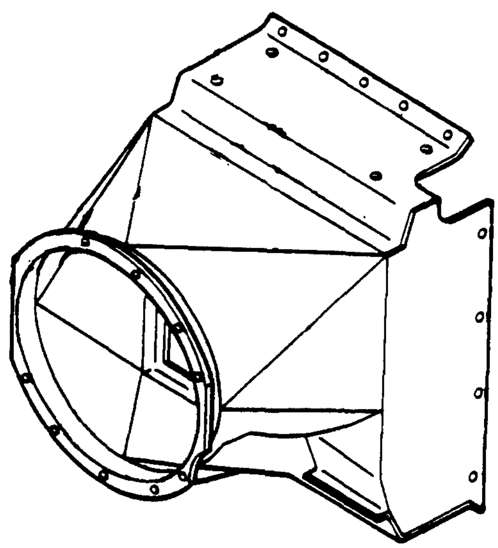

Figure 5-13. Oil Cooler Duct

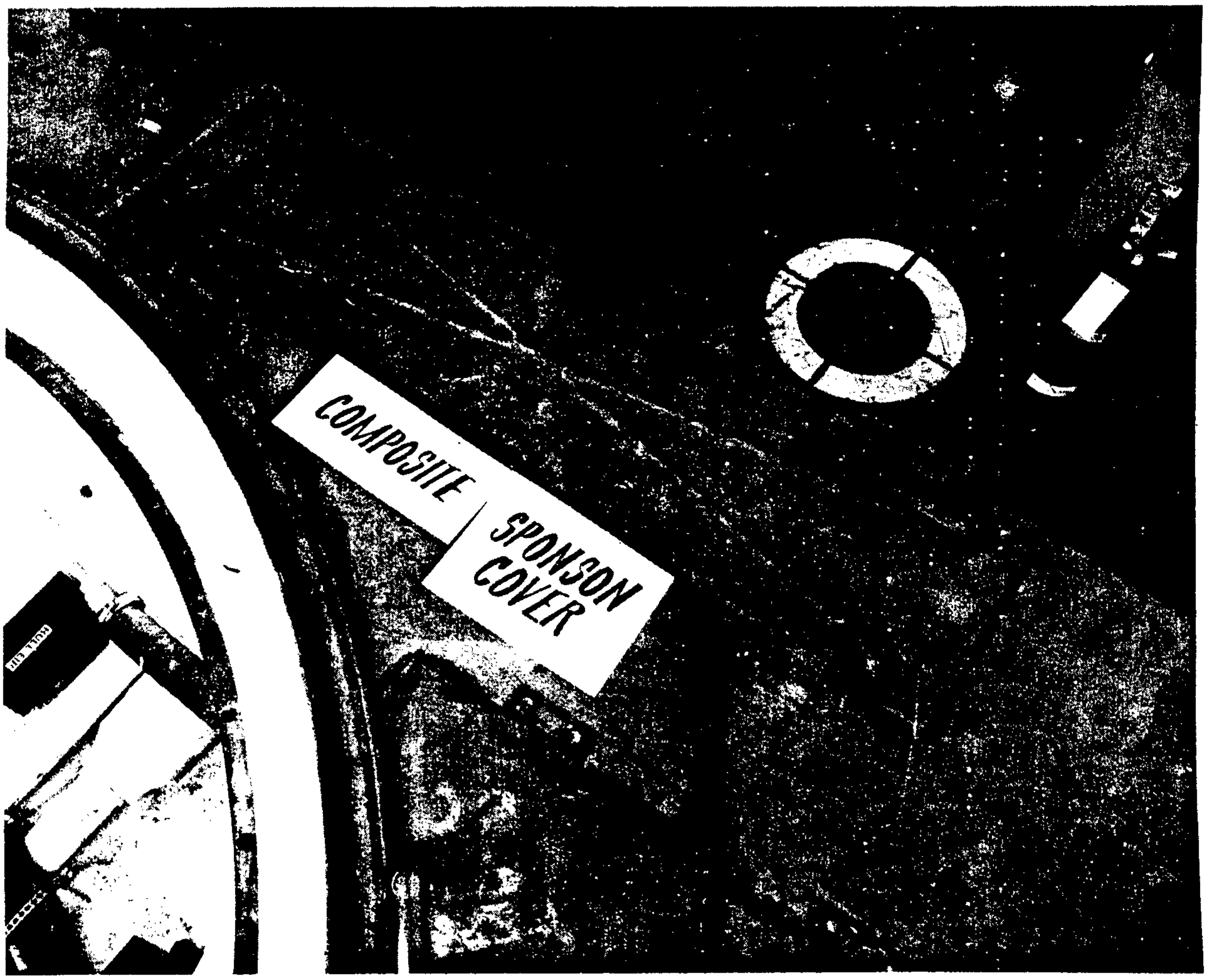

Figure 5-15. Composite Sponson Cover

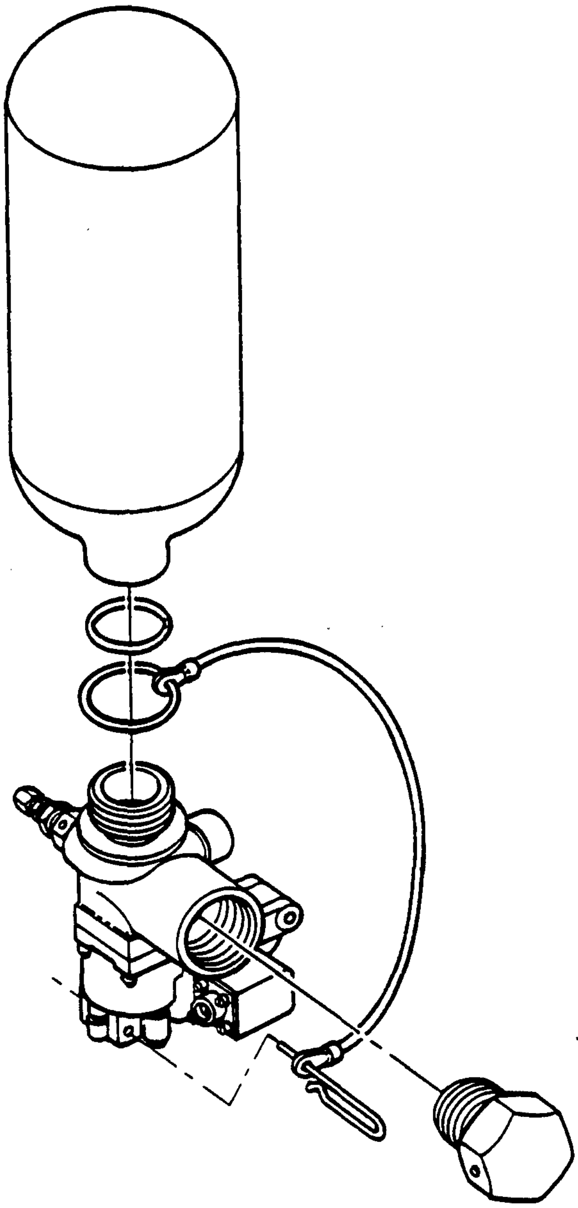

Figure 5-14. Fire Extinguisher Bottle and Valve

5.5.14. Gun Mount Tube (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Epoxy/E-Glass
Weight (lbs)	6	4
Cost (Engineering Estimate)	$175	$160

The gun mount tube and gun mount tube assembly act as thermal barriers for the gun. They protect the main weapon from the outside elements which could affect its performance. The gun mount tube is in between the evacuator chamber and the main section of the turret. It is currently fabricated from 1/16" aluminum sheet riveted together to produce a tapered tube. End fittings are located on each end to provide mounting points. The tube reaches a maximum temperature of about 250^{O} F in operation. In the future, both of the gun tubes will be supplied to GDLS with the 120mm gun.

The taper of this tube precludes the fabrication of a composite tube by the pultrusion method. This tube should be filament wound with one of the end fittings integrally wound in place. This reduces the required assembly time. The remaining end fitting would be bonded in place. Figure 5-16 shows a sketch of this tube.

5.5.15. Gun Mount Tube Assembly (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Epoxy/E-Glass
Weight (lbs)	31	19
Cost (Engineering Estimate)	$650	$235

The gun mount tube assembly is in between the evacuator chamber and the muzzle reference sensor (MRS) collimator on the end of the gun. This tube is presently made from 0.190" aluminum tubing with end fittings riveted in place.

Fabrication of a composite tube would involve the pultrusion process. A straight tube would be pultruded out of an epoxy/E-glass composite, cut to length, and the present end fittings would be bonded into place. There are currently plans to fabricate a prototype of this tube by the filament winding process under GDLS Internal Research and Development funds for 1986. The tube assembly is shown in Figure 5-17.

5.5.16. Tubiaxial Fan Housing (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Nylon
Weight (lbs)	3	1
Cost (Engineering Estimate)	$123	$55

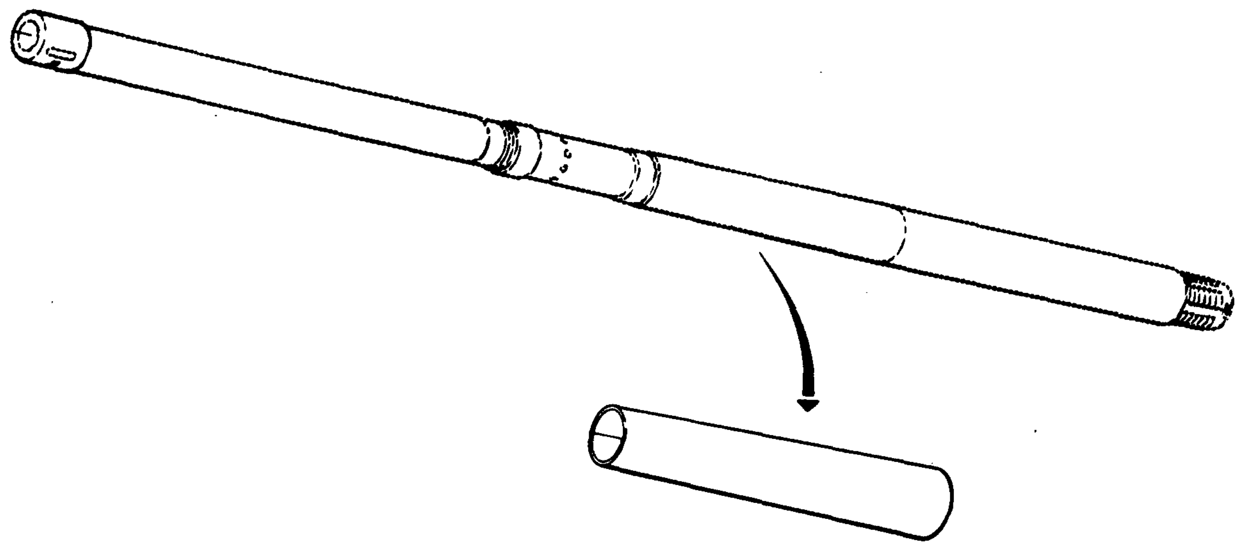

Figure 5-16. Gun Mount Tube

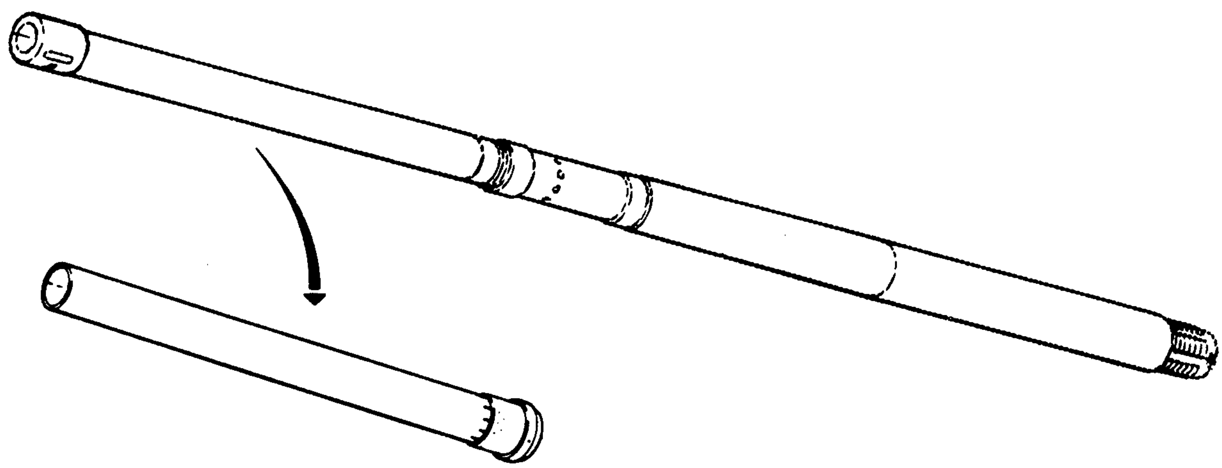

Figure 5-17. Gun Mount Tube Assembly

The tubiaxial fan housing is between the scavenger duct and the pre-cleaner assembly. Its purpose is to duct air between these components. The high Figure of Merit is due to the potential life cycle and implementation cost savings.

This component is purchased by GDLS from an outside supplier. The concept developed is to manufacture this component using injection molded nylon. The air passing through this component is at an atmospheric temperature, and should not provide any difficulties. A sketch of the tubiaxial fan housing is shown in Figure 5-18.

5.5.17. Torsion Bar Cover (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Polyester/E-glass
Weight (lbs)	99 total	59 total
Cost (Engineering Estimate)	\$55	\$14

The torsion bar cover protects the torsion bars from damage. Since the torsion bar is highly stressed, any damage from impact with another object or corrosion could severely shorten the bar's life. The current cover is made from .09" thick walled aluminum tubing 3.5" DIA. and approximately 70" long. Each end is flared to fit inside the torsion bar housings. Although the weight and cost savings per cover is not great, the total savings per tank and the easy implementation make this an attractive candidate.

The proposed cover would be pultruded using polyester and E-glass roving. The dimensions of the composite concept would be equivalent to the aluminum covers. A savings of 2.9 lbs per cover can be achieved. The torsion bar cover is shown in Figure 5-19.

5.5.18. Turret Platform (Figure of Merit = 59)

	CURRENT	PROPOSED
Material	Aluminun	Polyester/E-Glass/Honeycomb
Weight (lbs)	287	180
Cost (Engineering Estimate)	\$1,719	\$1,235

The turret platform contains all of the equipment that rotates with the turret. All of the crew members except the driver sit in this area of the tank. The platform consists of the turret floor which is fabricated from 1/2" aluminum, and the turrret basket support, post and bracket. The turret platform is one of the top ranked components for its potential to save weight and costs.

Two approaches can be taken in developing a composite turret platform. The first approach involves the development of composite components that would replace the current components part for part. For example, a composite turret platform floor would replace the present aluminum floor and a composite turret basket support would replace the metal turret basket support. This method would allow for one or more of the components to be replaced as the composite components are developed.

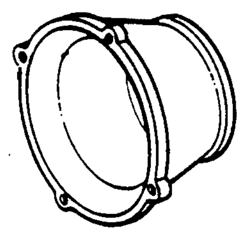

Figure 5-18. Tubiaxial Fan Housing

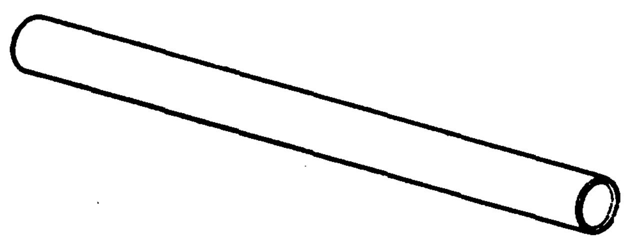

Figure 5-19. Torsion Bar Cover

The second approach to fabricating a composite turret platform is to replace the present turret platform floor, support post, bracket, and support with a single composite structure. It would have to be determined if this method is practical due to the large number of cutouts that would be required in what would be the turret platform sides.

In either approach, the method of fabrication would mainly consist of compression molding the components. A matched metal mold for this process would be expensive, but the expected savings in other areas of its fabrication are expected to offset this expense. The turret platform floor would have a honycomb core sandwiched between two layers of a composite skin. This method would produce a flat floor, which has not always been the case with the present aluminum floor as it can warp while it is being welded together. A composite turret platform floor would also have reduced fabrication time and eliminate all of the welding that is done on the present floor. Approximately 20 manhours are needed for the assembly and welding of the present floor. This could essentially be reduced to zero for a compression molded composite floor.

The turret basket support post, support, and bracket would also use compression molding if made separate from the floor, but the main section of the support post would be filament wound. The two turret basket concepts are shown below in Figure 5-20.

5.5.19. Turret Interior Stowage Boxes (Figure of Merit = 56)

	CURRENT	PROPOSED
Material	Aluminun	Cross-Linked Polyethylene
Weight (lbs)	26	17
Cost (Engineering Estimate)	\$192 - \$450	\$75 - \$295

The turret interior stowage boxes include: four ammo boxes, two vehicle accessory boxes, one container box, and one special equipment box. Each box is different and has its own special purpose. Currently these boxes are of a welded aluminum construction. There is a possible opportunity to save life cycle and implementation costs by replacements with an alternative material.

Some of these boxes should be replaced with rotational molded Nylon boxes. This material will provide the strength needed for storing items. In some of the ammo storage boxes, interior inserts would be needed which may not allow for a lower cost. Necessary hardware would be riveted or ultrasonically welded in place. Present mounting points will be used. Sketches of these stowage boxes are shown below in Figure 5-21.

5.5.20. Commander's Seat (Figure of Merit = 56)

	CURRENT	PROPOSED
Material	Steel	Epoxy/E-Glass
Weight (lbs)	104	50
Cost (Engineering Estimate)	\$385	\$325

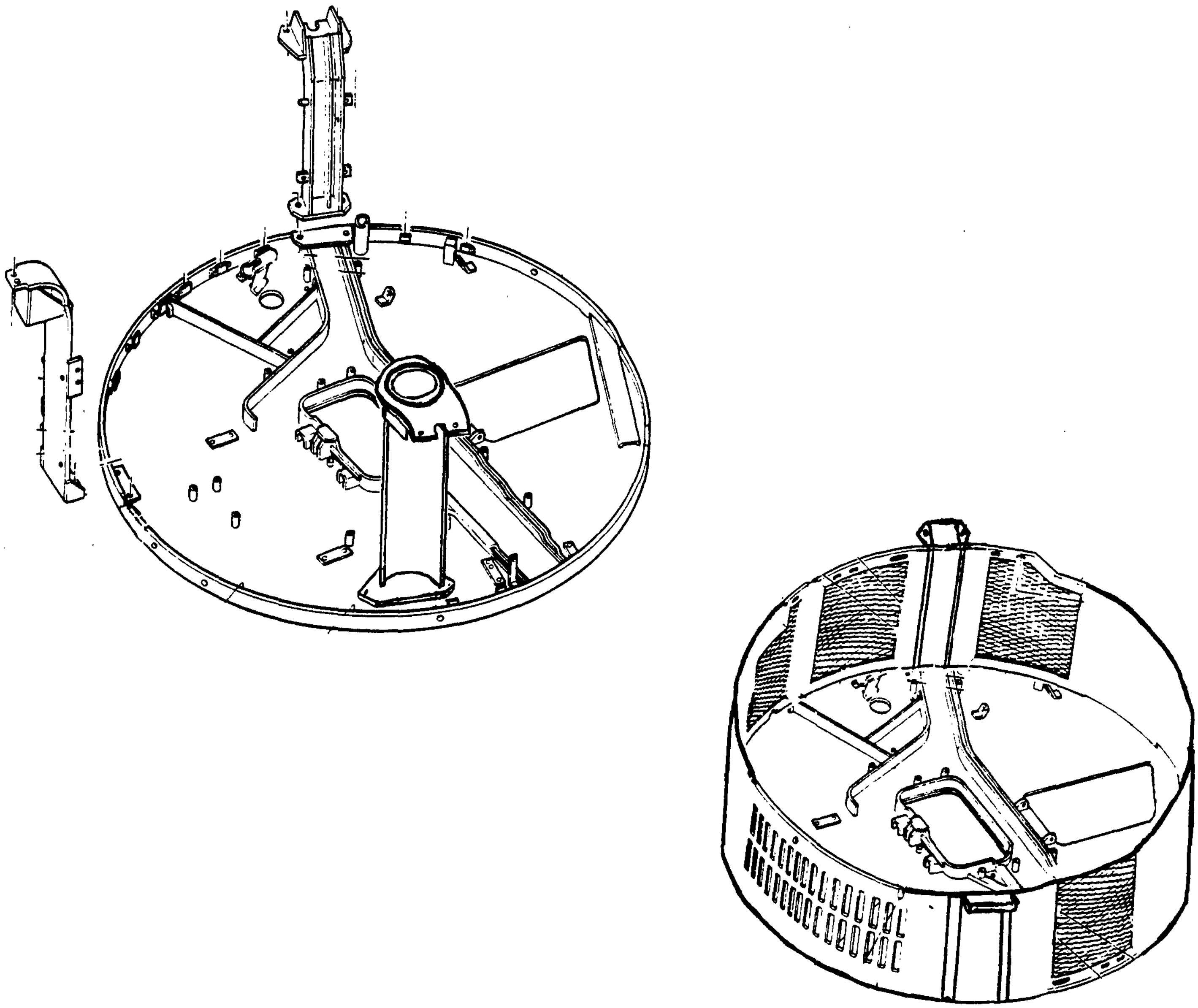

Figure 5-20. Composite Turret Platform Concepts

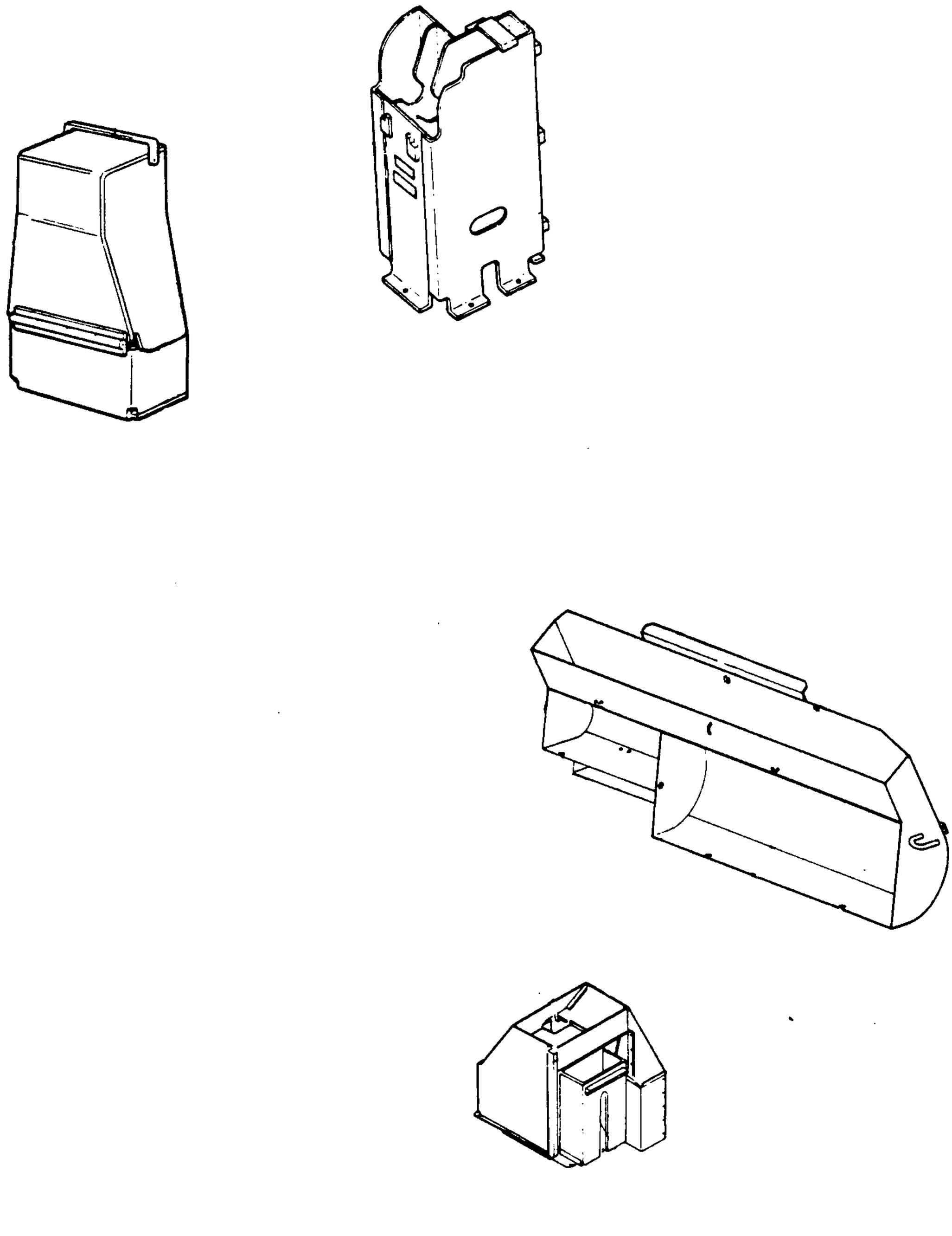

Figure 5-21. Stowage Boxes for the M1A1

The commander's seat is the most complicated seat in the tank. It is in the turret basket and is attached to the basket floor and side. Adjustments on the seat include seat and platform height. Both the bottom and back of the seat fold to vertical or horizontal positions as does the upper platform. With the exception of an aluminum intermediate platform, steel is used throughout the individual components. The commander's seat received its high Figure of Merit due to the potential weight svings from a change in material.

Composite replacement components for the commander's seat would include the seat back, the seat bottom, the basket attachment bracket, the column, and both platforms. These components would be fabricated using a fire retardant epoxy resin and E-glass fabric and mat. Most of the small metal components would be retained in addition to the platform support tube assembly and seat cushions. All of the composite components would be resin transfer molded using E-glass fabric and mat and vinylester resin, with the exception of the column which would be filament wound using E-glass/epoxy and a metal insert. The insert is needed to survive the repeated use of the adjustment mechanism. This concept for the composite commander's seat is shown below in Figure 5-22.

5.5.21. Wheel Hub (Figure of Merit = 56)

	CURRENT	PROPOSED
Material	Aluminum	HMC and XMC
Weight (lbs)	24	10
Cost (Engineering Estimate)	$95	$50

The wheel hubs rotate on the roadarm spindles, and provide a mount for the roadwheels. They are currently made of aluminum forgings. There are a total of 16 wheel hubs per tank. The potential weight savings resulted in ranking this component in the top 22 by the Figure of Merit rating system.

The main difficulty in designing a composite wheel hub is the development of the mounting section for the roadwheel if a direct substitution of this component is required. There are ten equally spaced holes around the outside edge of the wheel hub for mounting the roadwheel using studs. A composite hub must have more material around the holes than the aluminum hub. However the geometry of the roadwheel and hub will not allow for the additional material. Therefore, metal inserts for the mounting areas are needed. A more ideal situation would be to redesign the roadwheel and wheel hub together. This would allow for a more efficient composite design.

The method of fabrication for a composite wheel hub would be compression molding using high strength molding compound, (HMC), and XMC. Although matched metal molds are expensive, this cost would be offset by the relatively large number of parts, (approximately 13,500 parts per year), being made. A wheel hub is shown below in Figure 5-23.

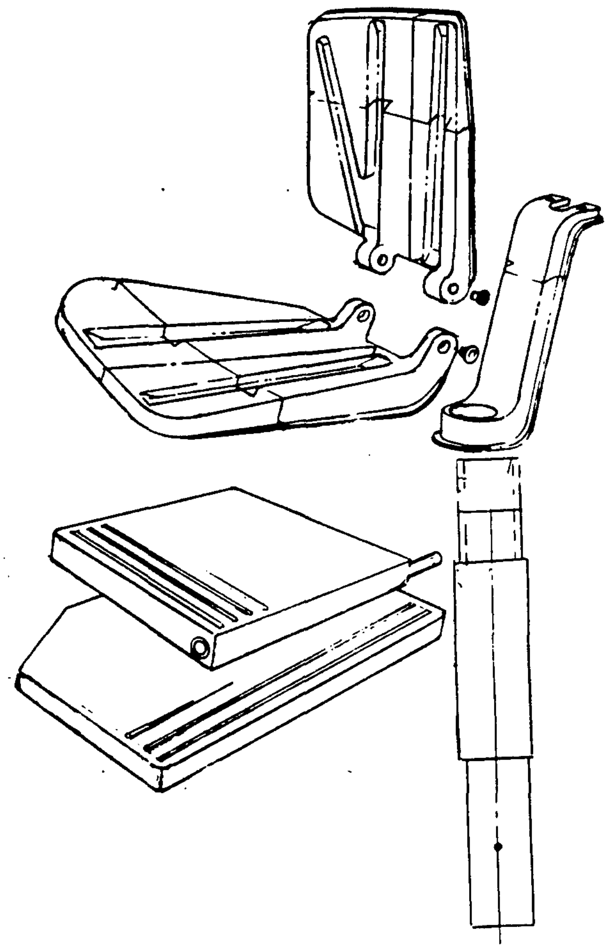

Figure 5-22. Commander's Seat Concept

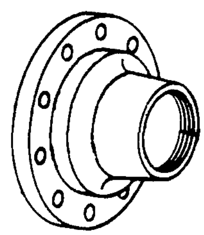

Figure 5-23. Wheel Hub

5.5.22. Torsion Bar (Figure of Merit = 56)

	CURRENT	PROPOSED
Material	Steel	Graphite/Epoxy
Weight (lbs)	123	46
Cost (Engineering Estimate)	$337	$850

There are 14 torsion bars in the bottom of the hull. They are approximately 3" in diameter and 84" long with a spline on each end. Their purpose is to act as the springs of the suspension. One end of each bar is fixed to the side of the hull through the torsion bar housing. The remaining end is splined to the roadarm. As the roadarm pivots about its axis, the torsion bar is twisted. The resistance to twisting is the spring force in the suspension. The torsion bar is required to take 520,000 in-lb of torsional load through 65 degrees of twist. The current torsion bar is highly stressed and any corrosion or pitting of the steel can cause a failure. The torsion bar received its high ranking due to the potential weight savings.

Due to the performance requirements of the torsion bar, a composite replacement would have to be maintained. A high performance resin is also needed. A composite torsion bar would be filament wound with ± 45 degree fibers. The main difficulty in achieving the performance required with a composite replacement is in the design of the end fittings which interface between the composite bar and the female splines in the roadarms and torsion bar housings. If a suitable design for these fittings can be developed, there may be a failure in the composite, but this can only be discovered through testing.

Development of a composite torsion bar is being undertaken at GDLS under Internal Research and Development funds. To date, two bars have been built and tested with failures occuring in the end fittings. A composite torsion bar is shown below in Figure 5-24.

5.6. Material Availability

All of the materials suggested for use in the composite applications concepts are readily available from domestic suppliers, with the exception of the intermediate modulus graphite fiber needed for the torsion bar. This material is not currently being produced in the quantity needed to fabricate enough torsion bars to support current tank production. However, within the next several years, sufficient production capacity will be available at several domestic carbon fiber manufacturers. No strategic materials have been suggested for use in any of the concepts.

5.7. Components with Extended Lives

Components fabricated from organic composite materials can in some cases have extended lives over their metal counterparts. In components which experience a cyclic loading and fail due to fatigue such as the current leaf springs used on some cars, composite materials have generally shown to have superior life. This is due to the inherent mechanical properties of these materials, and also it is due to their resistance to corrosion, which can cause premature failure in metals.

Figure 5-24. Composite Torsion Bar

Most of the components examined in this study are designed to last the life of the tank, however of the 49 components examined, only the torsion bar, if made from composite materials, may provide extended life when compared to its metal counterpart. This component is discussed below, and was chosen based on the relatively high maintenance factor (the maintenance factor for a component is the estimated number of components needed to support 100 vehicles for 20 years).

5.8. Long Term and Near Term Components

Most of the components examined are near term applications. All of the 22 top ranked components use present day technology, and of these components only the torsion bar and the final drive hub require relatively large development efforts.

Of the remaining components, there are three that stand out as being long term applications. These three are the ammo doors, the gun barrel, and the track pads. Of these three, the gun barrel may be the most promising application. The Benet Weapons Laboratory in Watervliet, NY, has initiated a program to develop a long 105mm gun tube. They have built several standard length tubes and two long tubes using a steel tube overwrapped with a graphite fiber composite. Test results appear promising.

Ammo doors and track pads encounter very rough environments. The development of these components using composite materials is a challenging undertaking, and only time will tell if it is ever accomplished.

The other lower ranked components are near term applications, however some are not feasible considering the cost associated with the weight savings gained. These applications may become more attractive in the future as material and manufacturing prices decrease, or new technological developments are made.

The ultimate composite application would be the design and fabrication of composite frame and skin vehicle such as the Mission Adaptive Platform being developed by GDLS. This composite vehicle uses applique armor, which is supported by the frame and skin, for protection. Large weight savings are possible with this type of construction.

5.9. Flammability of Composites

Flammability of composite materials and plastics used inside vehicle compartments occupied by human being is an area of great concern. This concern is magnified when dealing with a tank type vehicle in battlefield conditions where the crew may not be able to exit the vehicle without endangering their lives. Proper standards must be implemented in order to ensure a crews' safety in this type of atmosphere.

Parameters used to characterize the performance of material in a fire include:

(1) Combustibility

(2) Flame Spread

(3) Smoke Generation

(4) Toxicity

(5) Rate of Heat Release

(6) Oxygen Consumption

Most of the current standards are based on the combustibility of a material, and do not take into account the remaining parameters.

An examination of the flammability of composite materials revealed that the most common industry standards in use are the UL94 standard, Tests for Flammability of Plastic Materials;[5] Motor Vehicle Safety Standard No. 302,[6] Flammability of Interior Materials, and the Federal Aviation Regulation (FAR) Section 25.853.[7] All three of these specifications require certain burn rates in order for the material to pass.

The Underwriters Laboratory "Test for Flammability of Plastic Materials", standard rates a material as 94 V-0, 94 V-1, or 94 V-2. The "V" designates a verticle burn test. The main requirements needed to obtain a 94 V-0 rating are listed below. A material must not:

1. burn for more than ten seconds after flame application
2. have a total combustion time exceeding 50 seconds for ten flame applications
3. drip particles that ignite dry cotton 12 inches below the specimen
4. have glowing combustion that persists for more than 30 seconds after the second flame application.

To obtain a 94 V-1 rating, a material must not:

1. burn for more than 30 seconds after the initial flame application
2. have a total combustion time of more than 250 seconds for ten flame applications
3. ignite dry coton placed 12 inches below the specimen
4. have glowing combustion for more than 60 seconds after the second flame application

Finally, to receive a 94 V-2 rating, a material must meet the V-1 rating with the exception of being allowed to ignite the cotton located below the test sample.

The Motor Vehicle Safety Standard No. 302 essentially does not allow a material to burn at a rate exceeding four inches per minute during a horizontal burn test, and the FAR standard specifies that a material must be slow burning, i.e. it must be self-extinguishing in a verticle orientation when subjected to a small flame. The use of materials that meet this standard reduces the probability of ignition by a small flame, and the rate of flame propagation beyond the ignition source.

Additional research into the flammability of composite materials revealed that because the FAR standard considered only flammability, organizations such as the Federal Aviation Administration (FAA) and the National Bureau of Standards (NBS) are actively developing standards, and conducting flammability test. These organizations were contacted for information on flammability standards of composite materials.

The FAA originally made two regulatory proposals pertaining to toxicity and smoke. The proposed rules would have required materials used in crew compartments of aircraft to meet certain test criteria pertaining to smoke and toxic emissions. However, scientific response to the proposals was negative citing inadequate development of test methodology and the high cost of compliance along with a questionable safety benefit. Of particular concern was the inadequate relationship between smoke, flammability, and toxicity. These proposals were later withdrawn for further study.

Currently, the FAA recommends that the Rate of Heat Release method of characterizing burning composites be their official standard. This test is performed using the Ohio State University (OSU) rate of heat release apparatus standardized by the American Society for Testing and Materials (ASTM-E-906) as modified with an oxygen analyzer. The Department of Transportation must approve this recommendation in order for it to be adopted as an official standard. The NBS also recommends using this standard, although they have developed a bench scale apparatus for this purpose called the Cone Calorimeter.

Several full-scale fire tests using the fuselage of a military C-133 aircraft have been done. The test conditions simulated typical post-crash, external fuel-fed fires. Among other aspects of cabin fires, "flashover" (a condition in which certian gases and other products emitted during the combustion process are trapped in a confined space, reach their auto-ignition temperature and are ignited spontaneously) was also investigated. Another objective of this test was to determine the relationship between composite interior panel fire performance and the survivability in a fire situation.

Test results concluded that composite materials with low heat release rates (low flammability) improved the survivability in a cabin fire scenarios. The tests also show that materials with low heat release rates produce lower amounts of smoke and lower toxic gas concentrations than materials with high release rates (see Figure 5-26 and 5-27). Because of the correlation between flammability and smoke emissions, and the fact that fire growth is a more significant survivability factor than smoke alone, the FAA did not consider it necessary to establish a separate standard for measuring smoke emission characteristics.

By using a fire-proof coating on the panels, significant improvements in safety, or more specifically, a delay in the onset of flashover, could be achieved by lowering the heat release rate. Due to the total involvement of the cabin atmosphere, survival after flashover is nearly impossible. This is partially due to the findings that the level of toxic emissions after flashover were much higher than before flashover. Before flashover, it was found that toxic emissions were below the level needed to prevent occupant survival. A careful selection of materials can minimize the production of toxic gases, and provide enough time for a safe exit of the vehicle. The proposed standard requires the use of materials with high ignition temperatures, reduced heat release rates, and lower content of thermally unstable components, thereby reducing toxic emissions and smoke levels before flashover. The materials should also delay the onset of flashover. In addition to the rate of heat release test, the original FAR burn test would still have to be met.

To date, five composite materials intended to represent constructions suitable for use as aircraft interior cabin walls have been tested using the FAA method. These materials were of similar composition being considered for use in the tank. Specifically the materials were: epoxy/fiberglass, phenolic/fiberglass, epoxy/Kevlar, phenolic/Kevlar, and phenolic/graphite. Of the five materials tested, the phenolic/fiberglass panel tested well under all conditions. Also, some general statements can be made. Phenolic resins, which require special processing parameters, are generally more flame retardant than Polyesters, which in turn are more flame retardant than Epoxy resins.

The addition of flame retardant additives to the resin can greatly improve the flammability rating of the composite components, which may reduce the physical properties of the material. Also protective coatings can help to reduce flame spread. It appears that most composites can be made to meet the UL94 and MVSS, using halogenated additives and others such as antimony trioxide and bromine, with a minimal degradation of properties.

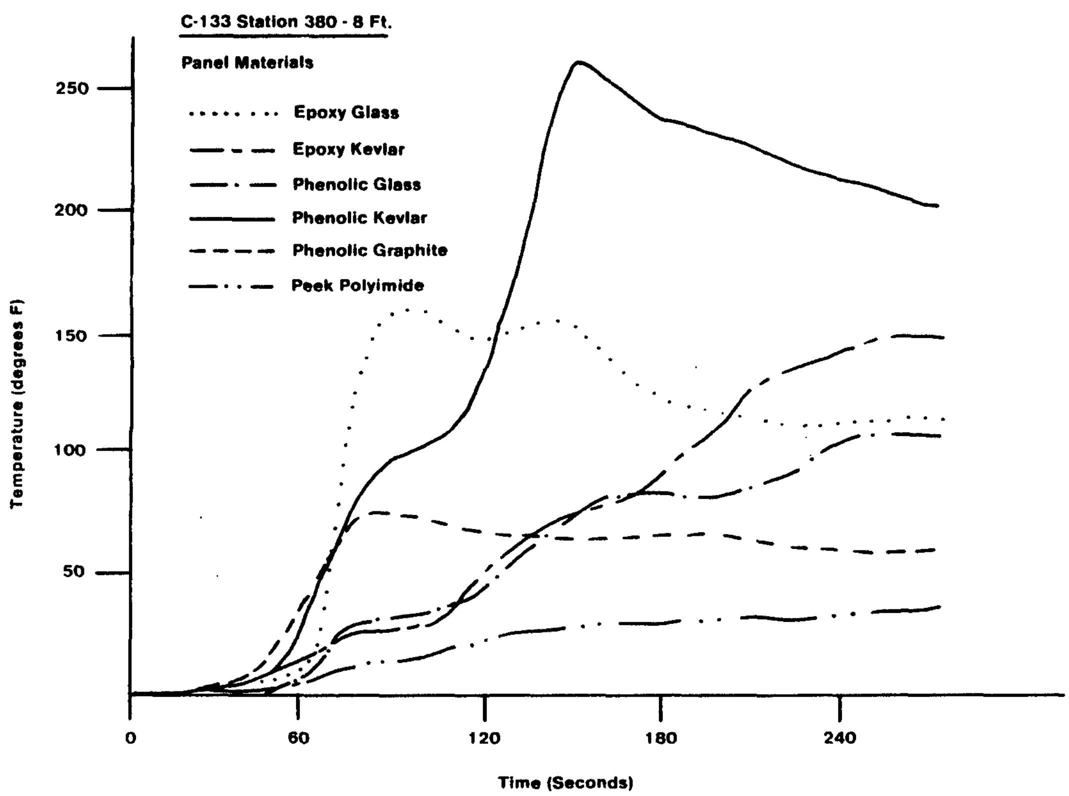

Figure 5-26. Heat Release of Various Composites

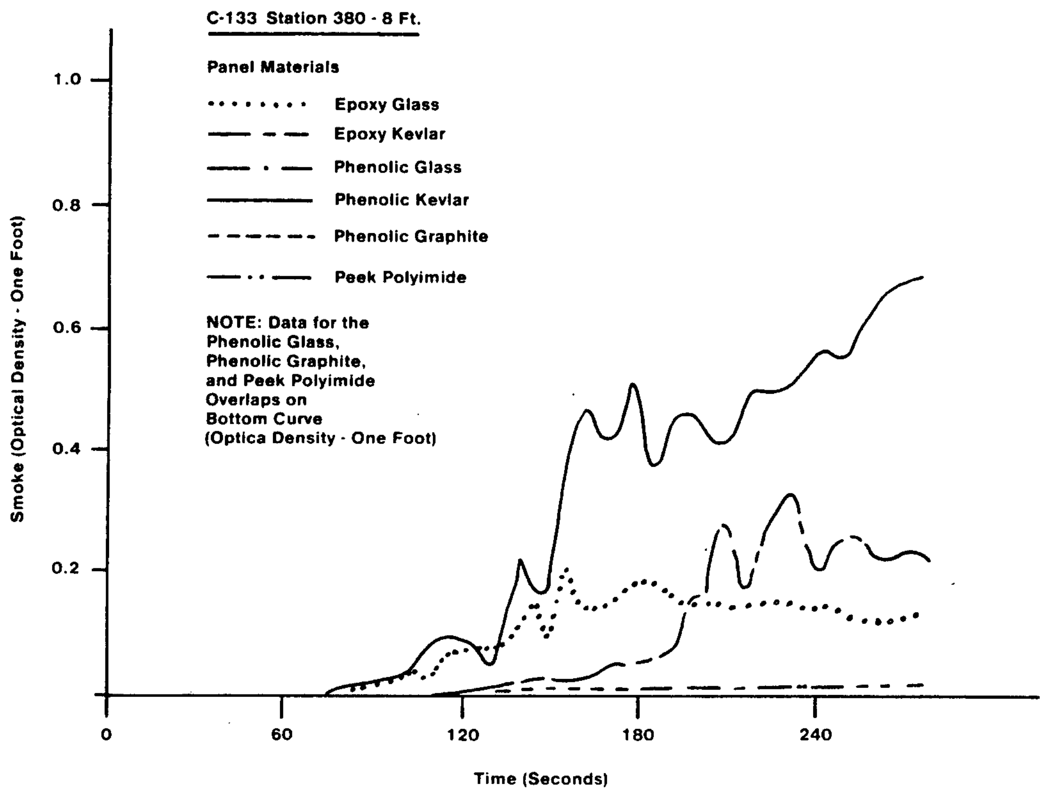

Figure 5-27. Smoke Production (Rate of Heat Release Method)

These additives are not without their disadvantages. The amount of smoke given off by a burning composite may increase with increasing amounts of flame retardants, and they may also decrease the physical properties of the material. Some toxic gases may be reduced with the addition of the flame retardants at the expense of more smoke being evolved. Specific materials need to be examined for critical locations. Various companies are producing new non-halogenated, non-phosphorus flame retardant additives for use in composities. These additives generally do not meet the performance of their halogenated counterparts concerning flammability. However they do generally produce less smoke and toxic gasses. They may allow occupants enough time to extinguish the fire or escape from a vehicle.

The effects of adding reinforcing material to resin matrix can vary. In most cases the reinforcement reduces the flammability of the composite due to its higher burn temperature. However, in some cases the reinforcement increases the flammability acting to hold the flaming material together. This suggests that the flammability of a composite depends on resin properties, reinforcement properties, and the amount of reinforcement. Any component that has a critical flammability requirement should be tested to ensure the necessary safe environment.

Existing test data from testing done by the FAA, NBS, aerospace industries, the Army, and others on fire performance should be compiled and analyzed. These test results can be used to predict peformance of specific potential composite tank components. Specific levels of performance can also be set for the rate of heat release method. This method appears the best for characterizing flammability of composite materials. However, questions on the effect of adding flame retardants to composites and testing using this method remain. Flame retardants decrease flammability but at the expense of increased smoke production. Does this method account for this?

The second recommendation is that independent testing be done on all materials before they are used on a tank. Increased performance can then be designed in through the use of additives, changes in geometry, or other methods.

5.10. Nuclear Biological and Chemical Warfare Agent and Decontaminant Effects on Composites

The intent of this phase of the program was to determine the optimum polymer materials for composite material components. A review of reports and data published by Government Agencies, Research Organizations, and Private industry has revealed the type of parameters which are most critical to survivability in an NBC environment.

The most important parameter to be considered was whether any degradation of the polymeric material occurs when it is contacted with either the chemical warfare agent or the chemical decontaminant. Degradation may be determined by either visual examination or by noticing a loss in tensile strength, flexural strength, modulus and/or a change in hardness. The organic composite materials proposed for use in future design show only slight, if any, loss in physical properties when exposed to chemical warfare agents. The decontaminants presently in use will have some effects on these materials. Since these effects have not been completely defined due to the "state of the art," all finished products should be coated for optimum protection.

Degradation is not the only facet that should be considered when determining the NBC compatibility of a material. The absorption rate is an important factor when dealing with porous materials such as plastics and elastomers. The absorption rate or diffusion rate

takes into consideration the absorption of an agent or decontaminant and the desorbtion of the material. A material with a high absorption rate and a low desorption rate would exhibit a condition that is not compatible for minimal susceptibility to NBC chemical warfare agents.

Coatings have been developed that are resistant to chemical warfare agents and compatible with the decontaminating compounds. These coatings are not always compatible with the plastic substrate. In some cases, adhesion may be a problem, while in others the solvent in the coating may cause degradation. To determine coatings which are suitable for this application, more testing is required.

A few of the organic composite materials and plastics proposed for use in future vehicle design and their NBC compatibility are presented in Table 5-7. The data presented is based on exposure of materials to HD (Mustard Gas) and GD (Nerve Agent) chemical warfare agents and DS-2 and STB decontaminants. This data was obtained from reports and testing by industry under Government Contracts, Governmental Agencies, and General Dynamics Internal Research and Development reports. In the case of composite materials the resin or binder was considered the driving component of the composite, and therefore the analysis was based on this portion only.

5.11. Coatings for Composites

A complete composite applications study requires investigation of coatings. Metal components require coatings to prevent corrosion. Additional corrosion protection is not usually required for composite materials. However, the composite may require a surface coating in order to seal the surface if it is porous, to protect it from solar degradation, or to reduce the potential fire hazard of these materials.

In certain cases the matrix material may not provide a good surface for adhesion. When this occurs the surface must be pre-treated to permit good adhesion of the applied coating. Pre-treatment of the substrate may be accomplished by flame treating, where the plastic substrate is heated to a temperature below the transition temperature. This treatment eliminates any foreign material present such as mold release coatings, oil, and other non-compatible materials. For the applied coatings to have good adhesion, application must be accomplished within a few hours after pre-treatment. With some composite structures it is possible to apply a special primer directly to the substrate followed by the proper coating material.

Most coating systems for plastic and composite structures require only pre-treatment and a top coat. The top coat can be either an epoxy or an urethane based coating. Either type will protect the substrate from chemical agents and will allow decontamination.

Another coating method called "In Mold Coating" has been developed to eliminate defects such as porosity, sink marks, short term waviness and other surface defects. This method involves the injection of a coating on the surface of a partially cured sheet molding compound (SMC) part. To do this, the press is backed off of positive pressure and the coating is injected under pressure. This method eliminates rework and post-finishing which results in coat savings.

Table 5-7. N.B.C. Compatibility with Composite and Plastic Materials

Material	Relative Sorbtion Rate		Type of Degradation
	CW Agent	Decontamination Agent	
Nylon 6/6	Low	Medium	Loss in Strength in DS-2
Glass Fabric/Epoxy	Low	Low	Slight Loss in Strenth in DS-2
Teflon	Negative	Negative	None
Polyethylene	Medium to Low	Low	Loss in Strength and Hardness in STB

Several types of coatings are currently being used for "in mold coating" including two-component urethanes and one-component hybrids. Reapplying pressure to these materials injected onto the partly cured component fully cures the component within 30 to 60 seconds. With advanced formulation SMC and reduced cycle time for the coating, only a small amount time is added to molding a SMC component. Further study is required to prove these types of coatings in an NBC environment, and their performance after decontamination.

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3 Direct Support and General Support Maintenance Repair Parts and Special Tools Lists, Tank, Combat, Full-Tracked: 120mm Gun, M1A1 Hull

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APPENDIX A: SHOCK AND BALLISTIC DATA

3.1.1 Component Location. The requirements contained herein are applicable to components installed in or on the XM1 tank as follows:

Location A	Turret interior excluding the bustle
Location B	Turret bustle interior
Location C	Hull driver's compartment
Location D	Hull engine compartment
Location E	Hull mid-section interior
Location F	Turret exterior
Location G	Hull exterior

3.1.2 Component Mounting Sublocation. Component mounting interface sublocation is defined as follows:

Sublocation A1	Turret basket wall or support
Sublocation A2	Turret basket floor
Sublocation A3	Turret armor walls, forward of bustle
Sublocation A4	Turret ceiling, forward of bustle
Sublocation A5	Turret ammo compartment door, crew side
Sublocation A6	Turret electronic omponent rack
Sublocation A7	Recoiling portions of the main weapon
Sublocation A8	Non-recoiling portions of the main weapon and main weapon mount
Sublocation B1	Turret bustle interior walls
Sublocation B2	Turret bustle interior ceiling
Sublocation B3	Turret bustle floor
Sublocation B4	Turret ammo compartment door, bustle side
Sublocation C1	Driver compartment side walls
Sublocation C2	Drive compartment forward wall and ceiling
Sublocation C3	Driver compartment floor

Sublocation D1	Engine compartment side walls
Sublocation D2	Engine compartment rear walls
Sublocation D3	Engine compartment ceiling
Sublocation D4	Engine compartment floor
Sublocation D5	Engine/transmission/final drive
Sublocation E1	Hull mid-section walls
Sublocation E2	Hull mid-section floor
Sublocation F1	Turret exterior top surface forward of bustle
Sublocation F2	Turret exterior sides forward of bustle
Sublocation F3	Main weapon mount and guard
Sublocation F4	Recoiling portion of main weapon, exterior
Sublocation F5	Turret exterior top surface of bustle
Sublocation F6	Turret exterior sides of bustle
Sublocation G1	Hull exterior top surface forward of engine compartment
Sublocation G2	Hull exterior sides forward of engine compartment
Sublocation G3	Hull exterior bottom surface forward of engine compartment
Sublocation G4	Hull exterior top surface of engine compartment
Sublocation G5	Hull exterior sides of engine compartment
Sublocation G6	Hull exterior bottom surfaces of engine compartment

TABLE A-1. GUN FIRING SHOCK LEVELS

Sublocation	** Level	* Duration	Direction (Axis)		
			Lat.	Vert.	Long
A1, A3, A5, B4, F2	100G	1.0 ms	X	X	
A1, A3, A5, B1, B2, B3, B4, F2, F5, F6	100G	1.0 ms			X
A2, C1, C2, C3, E1, E2, G1, G2, G3	100G	1.5 ms	X	X	X
D1, D2, D3, D4, D5, G4, G5, G6	55G	2.5 ms	X	X	X
B1, B2, B3, F5, F6	70G	1.0 ms	X	X	
A7, F4	400G	.5 ms	X	X	X
A8, F3	500G	.25 ms	X	X	X
A6	To be defined in the detailed component specification.				
A4, F1	100G	1.0 ms		X	
A4, F1	55G	1.7 ms	X		
A4, F1	225G	0.5 ms			X

*For test tolerances to be ± 0.2 ms except when specified pulse duration is 1.0 ms or less, the tolerance for second and subsequent shocks shall be ± 0.1 ms.

**Tolerance of shock shall be ± 10% of specified levels.

NOTE: The tabulated values are half-sine pulses whose universal equivalent static accelerations (shock spectrums) envelope ESA's which are mathematically derived from actual field Gun Firing shock transient measurements. This procedure generally yields conservative (overtest) results which are to be allowed for in shock test planning. This allowance particularly applies to large complex complex components know historically to survive field use but fail shock-machine testing.

3.2 Performance.

3.2.1 Functional. The component shall perform as specified in the detailed component specification during subjection to the environmental conditions identified in Table VII. for the component's installed sublocation. The environmental conditions will be imposed individually and/or in any combination thereof.

3.2.2 Degraded operation. Performance of the component shall not be degraded by more than 20% after subjection to the operatinal ballistic shock conditions of 3.1.3.18. Realignment and adjustment is permissible prior to performance testing.

3.2.3 Non-functional. The component shall perform as specified in the detailed component specification after subjection to the environmental conditions of cleaning spray (3.1.3.11), storage temperature (3.1.3.13), and gungus (3.1.3.15).

3.2.4 Electromagnetic interference and compatibility (EMI/EMC). The component (equipment and subsystems), when installed in the XM1 tank, shall not exhibit any malfunction or degradation of performance, beyond the operational tolerances of the individual component specification, from intra-system EMI. Intra-system EMI levels are as defined in MIL-STD-461A, Notice 4, Table I through Vll. The component , during operation, shall not generate EMI beyond the defined intra-system EMI levels.

3.2.5 Physical integrity. Components mounted in crew compartments shall remain intact and shall not become secondary projectiles when subjected to the high intensity shock conditions of 3.1.3.19.

TABLE A-2. OPERATIONAL BALLISTIC SHOCK LEVELS

LOCATION	SHOCK LEVEL (FIGURE 1) LAT.	VERT.	LONG.
A1	V	V	V
A2	V	V	V
A3	W	W	W
A4	W	W	W
A5	W	W	W
A6	W	W	W
A7	W	W	W
A8	W	W	W
B1	V	V	V
B2	V	V	V
B3	V	V	V
B4	V	V	V
C1	W	W	W
C2	W	W	W
C3	W	W	W
D1	V	V	V
D2	V	V	V
D3	V	V	V
D4	V	V	V
D5	V	V	V
E1	W	W	W
E2	W	W	W
F1	W	W	W
F2	W	W	W
F3	W	W	W
F4	W	W	W
F5	W	W	W
F6	W	W	W
G1	W	W	W
G2	W	W	W
G3	W	W	W
G4	W	W	W
G5	W	W	W
G6	W	W	W

NOTE: The tabulated values are half-sine pulses whose universal equivalent static accelerations (shock spectrums) envelope ESA's which are mathematically derived from actual field test ballistic shock transient measurements. This procedure generally yields conservative (overtest) results which are to be allowed for in shock test planning. This allowance particularly applies to large complex components known historically to survive field use but fail shock-machine testing.

TABLE A-3. HIGH INTENSITY SHOCK LEVELS

LOCATION	SHOCK LEVEL (FIGURE 1)		
	LAT.	VERT.	LONG.
A1	X	X	X
A2	X	X	X
A3	Y	Y	Y
A4	Y	Y	Y
A5	Y	Y	Y
A6	U	U	U
A7	Y	Y	Z
A8	Z	Z	Z
B1	X	X	X
B2	X	X	X
B3	X	X	X
B4	X	X	X
C1	Y	Y	Y
C2	Y	Y	Y
C3	Y	Y	Y
D1	W	W	X
D2	W	W	X
D3	W	W	X
D4	W	W	X
D5	W	W	X
E1	Y	Y	Y
E2	Y	Y	Y
F1	Y	Y	Y
F2	Y	Y	Y
F3	Z	Z	Z
F4	Y	Y	Z
F5	Y	Y	Y
F6	Y	Y	Y
G1	Y	Y	Y
G2	Y	Y	Y
G3	Y	Y	Y
G4	Y	Y	Y
G5	Y	Y	Y
G6	Y	Y	Y

NOTE: The tabulated values are half-sine pulses whose universal equivalent static accelerations (shock spectrums) envelope ESA's which are mathematically derived from actual field test ballistic shock transient measurements. This procedure generally yields conservative (overtest) results which are to be allowed for in shock test planning. This allowance particularly applies to large complex components known historically to survive field use but fail shock-machine testing.

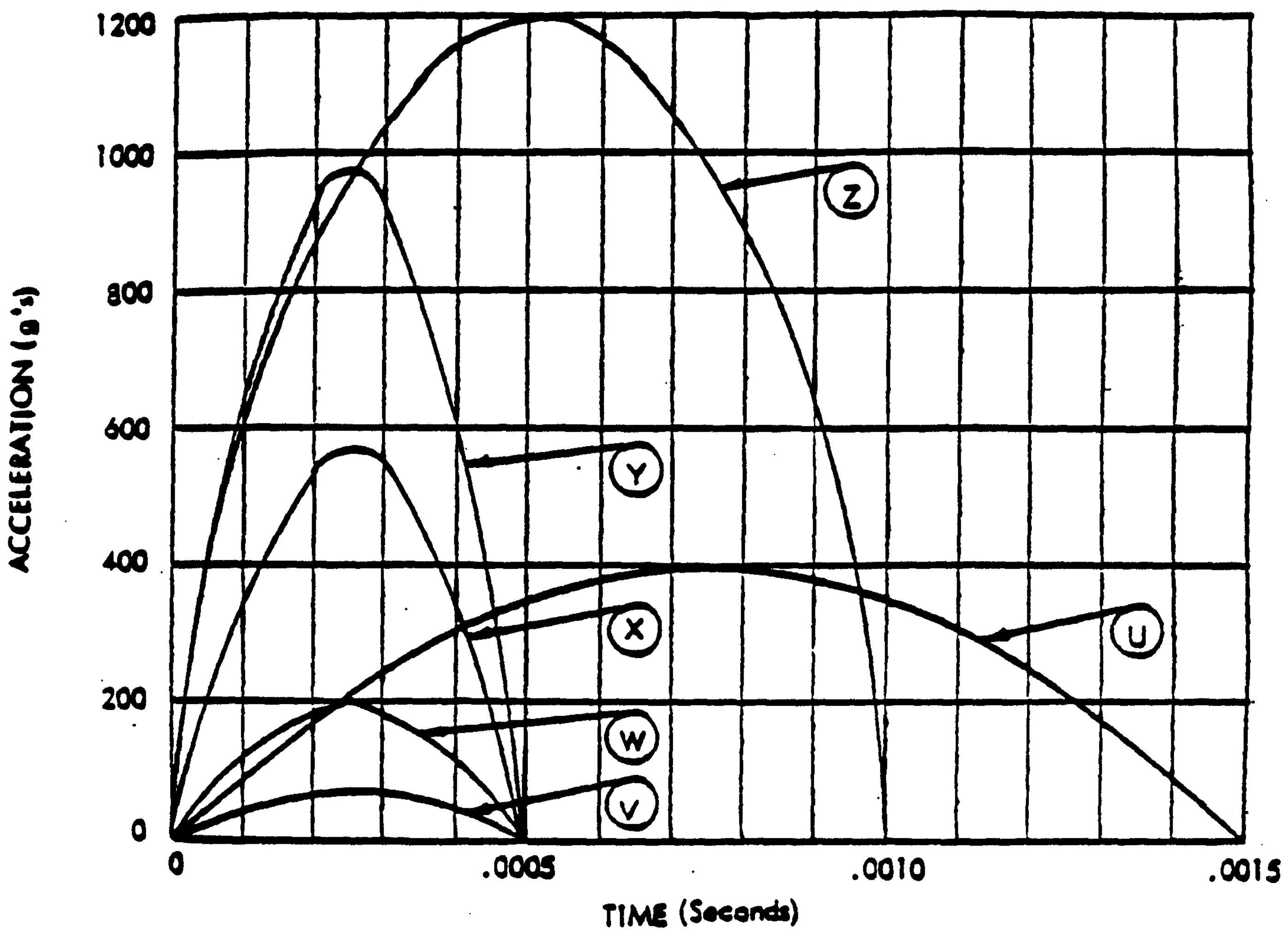

Figure 1. Equivalent Input Shock Pulse.